ABSTRACT

dissertation work of Mirzakhmedova Gulbanu Absamatovnaon the topic "Development and research of state dependent control synthesis algorithms for dynamic economic systems" presented for the degree of Doctor of Philosophy (PhD) in a specialty "6D070300 - Information systems"

The relevance of the research topic. The rapid development of information processes necessary to achieve management goals in any industry has brought the creation of information system components to the forefront. The growth in the volume of scientific, technical, political, and economic information for practical work in relevant areas of human activity creates the need for the widespread use of information technologies in management. Accordingly, in the scientific, technical and economic spheres, there is an increasing need for the development of information systems of various types. Today, the possibility of using economic and mathematical methods and models for making operational decisions, matching analytical data with specific processes, and analyzing specific financial and production conditions is relevant. Since the controls in such models are specific volumes of financing, then when planning, it is necessary to determine the optimal, from the point of view of one or another criterion, volumes of financing by industry, sector, and direction of the economy in order to transition over a given period time in one or another state of the economic system.

The research carried out in the dissertation relates to approaches to applying the SDRE methodology to economic systems, one of the most dynamically developing areas of mathematical control theory in recent years. The possibility of solving planning problems, where mathematical models can also contain restrictions on control values in the form of closed sets, was obtained for the first time in the SDRE approach. The dissertation work included investments in sectors of the country's economy, determination of balance sheet relations of labour resources, creation of a database of statistical data, and mathematical modelling of three-sector closed economic systems. Breaking down the impact of a country's economy into sectors allows decisions to be made about the allocation of resources to a development strategy by assessing the effectiveness of each sector's share.

Based on the above, the relevance of the dissertation work:

- Determining the adequate amount of financing of sectors to bring the economic system to the desired state over a certain period when planning the effective allocation of resources, since the problem of financing industries arises as management in economic models.
- Considering the limited resources allocated and the nonlinearity of the economic model, due to the complexity of the mathematical model being created, in the short- and longterm planning of economic systems, it is advisable to constantly develop approaches to the balanced distribution of labour and investment resources and search for new approaches.

The purpose of the research:

- Study of information system parameters for a three-sector economic model described by ordinary differential equations and a system of algebraic equations.
- Creation of an algorithm for constructing synthetic control for a three-branch economic model described by ordinary differential equations and a system of algebraic equations.

Research objectives:To achieve the goal set in the dissertation, the following problems are considered

- Creation of a database taking into account the main commodity stocks distributed by sectors of the country's economy, the volume of production in these sectors and the number of employees;
- Development of a module for the distribution of limited resources for an information system for managing economic sectors;
- Processing of numerical solutions to problems of managing the distribution of limited labour and investment resources for short-term and long-term planning of nonlinear economic systems;
- Programmatically implement an algorithm for planning resource allocation, considering the restrictions imposed on investment and labour resources in economic systems.

The object of the research is a mathematical model of a three-sector economic system, which is described by a system of nonlinear ordinary differential equations and nonlinear algebraic equations.

The subject of research: determination of labor and investment resources for a threesector economic model that ensures balanced economic growth.

Research methods: Krotov extension method, Lagrange multiplier method, successive approximation method, SDRE method, programming languages.

The scientific novelty of the research work.

- An algorithm has been developed for the synthesis of a nonlinear feedback controller for nonlinear systems (SDC) on an unlimited interval based on the SDRE approach, which is distinguished by the presence of special functions $\lambda_1(t), \lambda_2(t)$ to ensure the distribution of investment and labor resources balance ratios in long-term planning of three-sector economic systems.
- An algorithm has been developed for the synthesis of a nonlinear feedback controller for nonlinear systems (SDC) on a finite interval based on the SDRE approach, which is distinguished by the presence of special functions $\lambda_1(t), \lambda_2(t), W(t), q(y,t)$ to ensure distribution of investment and labor resources balance ratios in short-term planning of a three-sector economic system.

The main provisions of the dissertation submitted for defense:

- Study the economic model for the distribution of investment and labour resources when performing balance sheet relations and create an information system module that implements an algorithm for solving management problems for economic systems;
- Application of an information system module in the process of short-term and long-term planning for a nonlinear three-sector economic model of an object;
- Creation of synthesis control, which depends on the state of the trajectory for nonlinear dynamic systems for planning resource allocation;

The results obtained are used to distribute economic sectors into sectors that ensure balanced growth of the country's economy and to plan the effective distribution of investment and labour resources in these sectors.

<u>Theoretical and practical significance of the study.</u> The use of the method of Lagrange multipliers of a special type for a mathematical model of a three-sector economic system, given by balanced relative balance ratios, makes it possible to plan a sector economy.

Structure and scope of the dissertation work. The dissertation work consists of an introduction, four sections, a conclusion, a list of references and 3 appendices. It is 114 pages of typewritten text, which includes 6 tables, 20 figures.

The introduction reflects the relevance of the topic of the dissertation work, the purpose of the research work, the objectives of the research work, the object of research, the subject of research, the method of research, the scientific novelty of the research work, the

main conditions for the defense are formulated. There is also a list of articles published in the course of the study.

In the first section, the concept of nonlinear economic systems is given, an overview of works on the study of management accounting of three-sector economic systems, the work of scientists who have studied sectoral economic systems. The mathematical formulation of the problem of managing economic systems will also be presented.

In the second section, a mathematical representation of this system is given by introducing new designations into nonlinear economic systems defined by a system of differential equations, the problem of stabilization, synthesis of nonlinear systems whose coefficients depend on the control object is considered. The analytical solution of control problems of nonlinear systems is determined, the limits of the trajectory of which are set by various constraints, and algorithms for their solution are constructed.

The third section provides a summary of the concept of an information management system, the history of their occurrence. We present an algorithm for solving the problem of managing three-sector economic systems. The indicators and parameters of the economic system are determined. Using statistical data from an open data source database of the Agent of the Republic of Kazakhstan for statistics and planning, quantitative parameters of management accounting of a three-sector economic model are determined.

In the fourth section, in the second section, experimental calculation work is carried out on algorithms for determining the solution of effective management accounting for one class of economic systems, graphs of the trajectory of the system and effective management, effective distribution of labor and investment resources are constructed. For the quantitative parameter required to implement the algorithm, the parameters defined in the third section are taken.

The final section reflects the main results and conclusions of the dissertation work.

Applicant's contribution. The applicant obtained the main results on the construction of stabilizing and synthesizing control methods, the development of research methods, algorithms for numerical calculations, and the interpretation of the results of computational experiments, tables, and graphs. Statements of optimal control problems for dynamic systems and methods for their solution were proposed by the supervisor Z.N. Murzabekov and agreed upon by the foreign consultant M.G. Dmitriev.

Approbation of the results of the dissertation. The main content of the dissertation was discussed at scientific seminars and reported at scientific conferences: "IV International scientific conference of students and young scientists "FARABI ALEMI", Almaty, April 11-15, 2017, KazNU; XLI International scientific and practical conference: "Innovative technologies in transport: education, science, practice", Almaty, 3-4 April 2017 and 18 April 2018, KazATC; "International Conference on Differential Equations and Dynamic Systems", Russia, Suzdal, 06 - 11 July 2018; III International Scientific Conference "Informatics and Applied Mathematics" c. Almaty, September 26-29, 2018, IICT MES RK; "23rd International Conference on System Theory, Control and Computing (ICSTCC)" Romania, Sinaya, 09 -11 October 2019; 17th International Asian School-Seminar "Problems of optimization of complex systems (OPCS21)", Novosibirsk, Russia, 13-17 September 2021. The dissertation work was discussed at the scientific seminars of the department "Information Systems", Kazakh National University named after Al-Farabi.

Publication of results.Published articles and scientific papers describe the results of research on the topic of the dissertation. During the scientific work, 18 scientific papers were written, including:

4 scientific article in a journal indexed by Scopus:

1. Murzabekov, Z., Milosz, M., Tussupova, K., Mirzakhmedova, G. «Problems of Optimal Control for a Class of Linear and Nonlinear Systems of the Economic Model of a

Cluster». *Vietnam Journal of Computer Science*, 2020, 7(2), p.109–127,<u>https://doi.org/10.1142/S2196888820500062</u>(Scopus 2021: CiteScore-1.3; Percentile- 26%)

- Murzabekov, Z.N., Mirzakhmedova, G.A. «Construction of Control with Constraints for Nonlinear Systems with Coefficients Depending on the Control Object State». *Journal* of Mathematical Sciences (United States), 2020, 250(1), p. 76–82, <u>https://doi.org/10.1007/s10958-020-04999-4</u>(Scopus 2021: Q3, CiteScore-0.6; Percentile- 13%)
- Murzabekov, Z., Milosz, M., Tussupova, K., Mirzakhmedova, G. «Development of an algorithm for solving the problem of optimal control on a finite interval for a nonlinear system of a three-sector economic cluster». *Eastern-European Journal of Enterprise Technologies*, 2022, 1(3-115), p. 43–52, <u>https://doi.org/10.15587/1729-4061.2022.252866</u>(Scopus 2021: Q2, CiteScore-2.0; Percentile- 38%)
- 4. Dmitriev, M., Murzabekov, Z., Mirzakhmedova, G.«An Algorithm for Finding Feedback in a Problem with Constraints for One of Nonlinear Control Systems». *Automatic Control and Computer sciences*, 2022, 56(7), p. 623-633. https://doi.org/10.3103/S0146411622070033

<u>4 articles in journals recommended by the Committee for Quality Assurance in the</u> <u>Field of Science and Higher Education of the Republic of Kazakhstan:</u>

- 1. МирзахмедоваГ.А., «Сызықты емес динамикалық жүйелерге арналған тиімді басқару есептерін зерттеу» *ҚазҰТЗУ хабаршысы* №3(121), 2017, 529-534 б.
- 2. Мирзахмедова Г.А., «Экономикалық кластерлерді басқару» *ҚазҰТЗУ хабаршысы* №3(127), 2018, 460-465 б.
- 3. МурзабековЗ.Н., МирзахмедоваГ.А. «Экономикалық кластер моделінің сызықты емес жүйесін оңтайлы тұрақтандыру есебі». *ҚазҰТЗУ хабаршысы* №1(131), 2019, с.152-158.
- Murzabekov Z.N., Mirzakhmedova G.A. «Stabilization of one nonliner system with coefficients depending on the condition of the control object», Journal of Mathematics, Mechanics and Computer science №1(101), 2019, p. 76-86.

3 articles have been published in foreign scientific journals:

- Макаров 1. Дмитриев М.Г., Мурзабеков 3.H., Д.А., Мирзахмедова Г.А. «Стабилизация в макроэкономической формально линейной системе управления в коэффициентами». технологии зависяшими Информационные от и №2, 2019, вычислительные системы, c. 3-13. doi: https://doi.org/10.14357/20718632190201
- 2. Дмитриев М.Г., Мурзабеков З.Н., Мирзахмедова Г.А., «Алгоритм нахождения обратной связи в задаче с ограничениями для одного класса нелинейных управляемых систем». *Моделирование и анализ информационных систем*, т.28, №3, 2021, с. 220-233, <u>doi: https://doi.org/10.18255/1818-1015-2021-3-220-233</u>
- Мурзабеков З.Н., Мирзахмедова Г.А., «Построение ограниченного управления для одного класса нелинейных систем с коэффициентами, зависящими от состояния объекта управления». Проблемы математического анализа, изд.: Новосибирск «Тамара Рожковская», 104, 2020г., с. 69-74

In the collections of international scientific and practical conferences indexed on the basis of Scopus, 2 scientific articles have been published:

 Dmitriev, M., Murzabekov, Z., Makarov, D., Mirzakhmedova, G., «SDRE based stabilization of the affine control system with the stationary linear part». 23rd International Conference on System Theory, Control and Computing, ICSTCC 2019 -Proceedings 2019, p. 739–743, Sinaia, Romania, https://doi.org/10.1109/ICSTCC.2019.8885437 (Scopus, Proceedings) Dmitriev, M., Murzabekov, Z., Mirzakhmedova, G., «Stabilizing Regulator in One Class of Continuous System with Control Constraints». *17th International Asian School-Seminar "Optimization Problems of Complex Systems"*, OPCS 2021- Proceedings, 2021 p. 23–27. <u>https://doi.org/10.1109/OPCS53376.2021.9588763</u> (Scopus, Proceedings) <u>5 scientific articles were published in the collections of international scientific</u>

<u>conferences:</u>

- 1. Мирзахмедова Г.А. «Динамикалық жүйелерге арналған тиімді басқарудың сызықты квадраттық есебі». «Көліктегі инновациялық технологиялар: білім, гылым, тәжірибе» атты XLI Халықаралықғылыми - практикалық конференция. 3-4 сәуір 2017 ж. т1, Алматы, 512-514 б.
- 2. Мирзахмедова Г.А., «Задачи оптимального управление для нелинейных динамических систем». *IV Международная научная конференция студентов и молодых ученых "ФАРАБИ ӘЛЕМІ"*. 11.04.2017-15.04.2017 г. Алматы: Қазақуниверситеті, 2017 с. 203-203
- 3. Мирзахмедова Г.А. «Экономикалық модельдің тиімді стационарлы күйін іздеу есебін шешу». *XLII Халықаралық ғылыми практикалық конференция*. 18 сәуір 2018ж. т2, Алматы, 343-346 б.
- 4. Мурзабеков 3. Н., Айпанов Ш.А., Мирзахмедова Г.А. «Конструирование ограниченного управления для одного класса нелинейных систем с коэффициентами, объекта зависяшими от состояния управления». Международная конференция по дифференциальным уравнениям и динамическим системам. Тезисы докладов, Суздаль, Россия, 6-11 июля 2018г., с.149-150.
- 5. Мурзабеков З.Н., Мирзахмедова Г.А. «Оптимальная стабилизация одной нелинейной системы экономической модели кластера». *Ш-Международная конференция «Информатика и прикладная математика»*, 26-29 сентября 2018г., Алматы, с. 154-163.

Received 1 author's certificate:

MirzakhmedovaG., MurzabekovZ. «Development of an algorithm for solving optimal control problems in the Maple environment» 5.01.2023.