ABSTRACT

the topic of the dissertation work:
“Development of smart-technology for control systems of complex objects based on artificial intelligence approaches” submitted for the
degree of Doctor of Philosophy (PhD) in
the specialty 6D070200 – “Automation and control”

SAMIGULIN TIMUR ILDUSOVICH

Due to the growth of new information technologies, there is currently significant progress in the area of creating modern control systems with the help of advances in the field of artificial intelligence. The largest companies producing high-performance control systems, such as Honeywell, Schneider Electric, Siemens, Yokogawa, Emerson, Allen-Bradley, are investing in the development of smart manufacturing technologies, industrial artificial intelligence, modeling of digital twins of enterprises and the application of big data analysis systems. The introduction of the concept of the fourth industrial revolution or "Industry 4.0" in the world implies the creation of highly efficient, environmentally friendly, flexible and safe production, which is focused on the digitalization of modern controls with the ability to analyze consumer behavior. The growth of computing power of personal computers and industrial controllers makes it possible to solve complex problems of production control, in which it is necessary to take into account a large number of parameters and restrictions, while allowing you to change control strategies in real time. The introduction of the concept of the fourth industrial revolution or "Industry 4.0" in the world implies the creation of highly efficient, environmentally friendly, flexible and safe production, which is focused on the digitalization of modern controls with the ability to analyze consumer behavior. The growth of computing power of personal computers and industrial controllers makes it possible to solve complex problems of production control, in which it is necessary to take into account a large number of parameters and restrictions, while allowing you to change control strategies in real time. Modern systems for modeling technological processes make it possible to perform experiments on digital twins of an enterprise, explore and develop control loops depending on the current state of a technological object, and introduce adjustments into supervisory control systems. At the same time, the hardware is characterized by high fault tolerance, through the introduction of additional data transmission channels, redundant controllers and controls. The flexibility of such equipment lies in the possibility of real-time software migration and scaling in case of an increase in production volumes.

Industrial artificial intelligence has been widely used in the aerospace, metallurgical, chemical, oil and gas and other industries. AI methods allow performing optimization calculations in cases of lack of information about the control object, can be successfully used for calculations in multidimensional and multiply connected control objects with a large number of input and output process variables.

Foundation and initial data for the development of the dissertation topic. The basis for scientific research is an extract from the protocol of the meeting of the

department "Automation and Control" of the Institute of Automation and Information Technologies of KazNTU named after. Satpaev №1195-d dated September 29, 2018, which approved the topic of the PhD doctoral dissertation, scientific and foreign supervisor for the specialty 6D070200 - "Automation and Control". The initial data for the research work were scientific publications and monographs on the project of the CS MES RK No. AP05130018 on the topic “Development of cognitive Smart technology for intelligent control systems for complex objects based on artificial intelligence approaches” (2018-2020), educational materials with training center "Honeywell Automation College Amsterdam", technical regulations with "Honeywell - Automatic Control Systems" LLP.

Rationale for the conducting the research work. The introduction of AI methods in industrial production is associated with a number of difficulties when commissioning in real industrial production:

a) most of the work on the application of metaheuristic algorithms is aimed at the study of SISO systems, while for MIMO systems, taking into account the influence of relationships, there is quite a bit of research;

b) used metaheuristic algorithms should have the following properties: ease of implementation; minimum requirements for computing resources; the ability to process data in real time; low device memory requirements.

Thus, there is a need to develop technology for the implementation of AI methods in solving the problems of managing complex MIMO objects in modern control systems, for example, in the Honeywell Experion PKS DCS.

Information about the planned scientific and technical level of development, patent research and conclusions from them. The modeling of the gas purification process in a distillation column and the calculation of intelligent controllers were carried out in the Mathwork MATLAB application package. The distillation column design and dynamic simulation to verify the results was performed using the Honeywell Unisim Design R470 software, which includes the Peng Robinson library. The development of a control system based on Honeywell C300 controllers was carried out in the Honeywell Experion PKS R501 product using the HMIWeb Display Builder tools for creating cognitive mnemonic diagrams, Configuration Studio for server hardware configuration, Control Builder for developing industrial controller control strategies, Enterprise Model Builder for developing an enterprise model, Quick Builder to set up a control station.

The relevance of the topic of dissertation research. The implementation of smart production technologies can increase the profitability of enterprises by introducing artificial intelligence methods into automatic control systems, increase the safety and environmental friendliness of enterprises. According to research by the ASM Consortium of Industrial Accident Management, the US economy loses more than $20 billion each year due to industrial accidents, which equates to 3 to 8% of lost industrial capacity. At the same time, it is said that from 20 to 25% of all losses can be avoided by the implementation of proper alarm management systems and the introduction of high-performance displays in production, for better staff awareness of the situation in an industrial enterprise.

Scientific novelty of the research topic. The dissertation work is devoted to the development of an intelligent control system for a complex industrial facility with a distillation column based on metaheuristic algorithms for the purpose of implementation in the Honeywell distributed control system, which uses classical PID controllers.

Experimental studies and simulation results were obtained on the example of a real complex industrial object of the oil and gas industry - a distillation column.

The scientific novelty of the ongoing research are:

- Development of modified quality criteria for a complex MIMO control system for a real industrial facility with a distillation column;

- Setting the parameters of PI controllers of a complex MIMO system, taking into account the proposed modified quality criteria based on artificial intelligence metaheuristic algorithms.

- Implementation of the obtained results into the distributed control system Experion PKS from Honeywell.

- Development of cognitive HMI-interfaces for operators and engineers of stations of a distributed control system, taking into account the psychophysical characteristics of a person.

The purpose of the work is to develop an innovative Smart technology for the control system of a complex oil and gas industry facility based on artificial intelligence approaches, such as: ant colony algorithm (ACO), dragonfly algorithm (DA), gray wolf optimization algorithm (GWO), cuckoo search algorithm (CS), genetic algorithm (GA) and artificial immune systems algorithm based on clonal selection (CLONALG), as well as its implementation for the Honeywell Experion PKS distributed control system.

The solution of the goal is achieved by performing the following tasks, where necessary:

1. Analyze the state and prospects for the development of artificial intelligence in modern industrial production.

2. Substantiate the structure of a SMART management system.

3. Build a model of a distillation column and perform a decoupling operation to reduce the influence of the interconnections of a multidimensional and multiply connected technological object.

4. Develop modified quality criteria for a complex control object in order to ensure the accuracy of regulation and the stability of transient processes.

5. Develop a program for calculating intelligent PI controllers, including the connection of artificial intelligence optimization algorithms, modified quality criteria for a complex control object and a model of the gas purification process, taking into account the decoupling matrix.

6. Perform a comparative analysis of the calculated controllers using the optimization algorithms ACO, GWO, DA, CS, GA, CLONALG for the developed modified quality criteria and choose the most appropriate option. Calculate the distillation column in the Unisim Design software product and perform dynamic modeling of the column, taking into account the calculated intelligent PI controllers. Summarize the results of the study.

7. Develop a control strategy for the gas purification process using PI controllers in the Experion PKS distributed control system. To develop cognitive mnemonic schemes for managing the gas purification process for operators or engineers of an industrial enterprise, taking into account the psychophysical characteristics of a person.

Object of study. The process of gas purification in a distillation column at an oil and gas enterprise is considered.

Subject of study. Methods and algorithms for intelligent control of multidimensional and multiply connected technological objects.

Tasks of research, their place in the performance of research work in general. The task of the study is to implement modern methods, approaches and algorithms of AI, the scientific results of which are successfully introduced into real industrial production in order to implement the control of complex technological objects characterized by a multidimensional and multiply connected structure.

Methodological base of research. Research work was carried out by performing practical research, taking into account theoretical materials. In the course of the experiments, bioinspired artificial intelligence algorithms were considered, such as: the ant colony algorithm; genetic algorithm; cuckoo search algorithm; dragonfly algorithm; gray wolf optimization algorithm; algorithm of artificial immune systems based on clonal selection. To implement the control of a complex object, the method of decoupling control for multidimensional and multiply connected processes was used.

Provisions submitted for the defense of the dissertation. For the defense of a doctoral dissertation, the author makes the following provisions:

1) The decoupling control model for the gas purification process, implemented in the MATLAB Simulink software product.

2) Developed modified quality criteria ISE_M, ITSE_M, IAE_M to control the multidimensional process of gas purification in a distillation column.

3) The developed structure of the SMART-system for controlling the gas purification process.

4) An algorithm for calculating the coefficients of PI controllers, taking into account the modified quality criteria using AI algorithms. Calculations and analysis of regulators performed using artificial intelligence algorithms.

5) Dynamic and steady state models with smart controllers implemented in Honeywell Unisim Design software.

6) The developed control strategy for the Honeywell Series C C300 controller, an enterprise model with software and hardware implementation, cognitive HMI displays for controlling the technological object - the distillation column.

The structure and volume of the dissertation. The dissertation work "Development of Smart-technology for control systems of complex objects based on artificial intelligence approaches" consists of an introduction, five main sections, a conclusion, a list of references from 107 sources and 8 applications. The work contains 118 pages, 49 figures and 9 tables.

The first section is devoted to an overview of modern achievements in the field of industrial process control using artificial intelligence methods.

The second section discusses the flow chart of the gas purification process in a distillation column (DC), configurations and types of DC.

Section three discusses the methods and algorithms necessary to perform control of a complex multidimensional and multiply connected DC object. Considers the "decoupling" method to reduce the impact of interconnections on the main control channels. The synthesis of the modified quality criteria necessary for the calculation of PI-controllers is carried out. AI algorithms that are most suitable for solving the problem are considered.

The fourth section is devoted to the development of software for calculating PI controllers, taking into account modified quality criteria based on bioinspired algorithms. An analysis of the effectiveness of the algorithms was carried out and the best combination of the developed quality criterion and the AI algorithm was selected.

Section 5 is devoted to the integration of an intelligent control system for a multidimensional and multi-connected control object - a distillation column based on metaheuristic algorithms (ACO, GWO, DA, CS) into the Experion PKS distributed control system from Honeywell. The issues of implementing a management strategy and creating cognitive displays to improve control efficiency are considered. Software has been developed with an interface for adjusting regulators based on the ACO algorithm. A digital twin of the column, developed in the Honeywell Unisim Design software, is considered.

In conclusion, the main results of the study and conclusions on the work are presented.

Conclusion. As part of the dissertation work, the following main results were obtained:

1) The statement of the task of research on the introduction of an intelligent SMART control system into real industrial production is formulated;

2) The architecture of a SMART control system for a complex object was developed using the example of a distillation column and industrial equipment from Honeywell;

3) The analysis of the mathematical model of the distillation column was carried out;

4) Modified control criteria have been formed, in accordance with the quality requirements for the technological process of gas purification in the distillation column;

5) Intelligent PI controllers for the distillation column control system based on the ACO, GWO, DA, CS, GA algorithms are synthesized, effectively minimizing the developed quality criteria.

6) The results of modeling the synthesis of intelligent PI controllers are obtained and the best control approaches are analyzed.

7) Developed software for SMART distillation column control based on distributed control system Honeywell Experion PKS.

8) Cognitive displays for the SMART control system of the distillation column have been developed, taking into account the features of vision and psychophysical characteristics of operators.

9) A digital twin of the technological process was created in the Honeywell Unisim Design software product, where the model was built in a steady state and in a dynamic mode.

Implementation of the research results. Two acts of implementing the results of scientific research have been received. The training program is integrated into the curricula of the Kazakh-British Technical University in the specialties "Automation and Control", "Chemical Technology of Organic Substances". The results of the work have also been implemented in Honeywell - Automatic Control Systems LLP, which is a regional representative of Honeywell International Inc.

Level of reliability and results of approbation. Based on the results of the research, 18 printed works were published, of which 2 were in the international high-ranking journals Scopus, two author's certificates for computer programs were received, as well as two acts of implementation. The list of published works is presented below:

1. Samigulin, T., Shiryayeva, O. Development of a smart-system for a complex industrial object control based on metaheuristic algorithms of swarm intelligence // WSEAS Transactions on Power Systems. – 2021. – Vol. 16. – pp. 231-240. SCOPUS (Q3, Cite Score 0.7, 25%)

2. Samigulina G., Samigulin T. Development of a cognitive mnemonic scheme for an optical smart-technology of remote learning based of artificial immune systems // Computer Optics. – 2021. – Vol. 45(2). – pp. 286-295. SCOPUS (Q1, Cite Score 4.4, 82%)

3. Samigulina G.A., Samigulin T.I. Review of modern approaches of artificial intelligence for control systems of complex objects // Problems of Informatics. - Novosibirsk, 2018. - No. 3. - P. 4-20.

4. Samigulin T.I., Samigulina G.A. Development of software for managing a complex object based on the ant colony algorithm // Proceedings of the X All-Russian Scientific and Technical Conference with the Intern. participation "Robotics and artificial intelligence". - Zheleznogorsk, 2018. - S. 119-123.

5. Samigulin G.A., Samigulin T.I. Author's certificate for the computer program No. 836. Certificate of entering information into the state register of rights to objects protected by copyright for the software "ACCO (Ant Colony for Complex Objects)" publ. December 6, 2018

6. Samigulin G.A., Samigulin T.I. Development of SMART technology for controlling a complex object using the ant colony algorithm. - Almaty: Bulletin of the Almaty University of Energy and Communications. No. 1 (44). - 2019. - S. 98-105.

7. Shiryaeva O.I., Samigulin T.I. Development of an artificial immune control system for a multidimensional object of the oil and gas industry // Bulletin of NTU "KhPI". Series: Informatics and modeling. - Kharkov: NTU "KhPI". - 2019. - 2019. - No. 13 (1338). - P. 155-165.

8. Shiryaeva O.I., Samigulin T.I. Comparative analysis of the adjustment of the regulators of the control system for the process of gas distillation through a distillation column based on Smart technologies // International scientific and

practical conference "Innovative IT and Smart technologies", dedicated to the 70th anniversary of Professor Utepbergenov I.T., March 20, 2019. –270-273c.

9. Shiryaeva O.I., Samigulin T.I. Analysis of the results of modeling the processes of the oil and gas industry based on Smart technologies // Proceedings of the Satpayev Readings: Innovative technologies are the key to the successful solution of fundamental and applied problems in the ore and oil and gas sectors of the economy of the Republic of Kazakhstan, 2019. - Volume 2. - 270-274c.

10. Shiryaeva O.I., Samigulin T.I. Modeling and decoupling of a complex system with optimal CLONALG-regulators // - Almaty: IV International Scientific and Practical Conference "Computer Science and Applied Mathematics", September 25-29, 2019.

11. Shiryayeva O., Samigulin T. CLONALG application to the PID-controller synthesis of MIMO-systems in oil and gas industry // Lublin: Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska. - 2019. - No. 3. - P. 50-53. DOI: 10.35784/iapgos.235

12. Shiryaeva O.I., Samigulin T.I., Panyukova D.V. Basic concepts of the development of an artificial immune system for a class of complex systems // Bulletin of KazNITU. - 2019. - No. 5. - P. 501-504.

13. Samigulin T.I., Shiryaeva O.I. Development of a smart-system for controlling a complex technological process in the oil and gas industry using bioinspired algorithms. Vestnik KBTU. - 2019. - T. 16. - Issue. 4. - S. 164-171.

14. Shiryaeva O.I., Samigulin T.I. Development of software for the implementation of negative selection technology for building an intelligent control system for the oil and gas industry // Almaty: KazNITU named after Satpayev, materials of the conference "Satpayev Readings -2020". - 2020. - S. 245-248.

15. Shiryaeva O.I., Samigulin T.I. Author's certificate for the computer program No. 11354. Implementation of Smart-technology for building a control system for technological processes in the oil and gas industry; publ. 07/14/2020. - 2s.

16. Shiryaeva O.I., Samigulin T.I. Implementation of SMART technology for building optimal systems based on modified algorithms // Bulletin of the National Technical University "Kharkiv Polytechnic Institute". Collection of scientific works. Series: Informatics and modeling. - Kharkiv: NTU "KhPI". - 2020. - No. 1 (3). - P.41-49.

17. Shiryaeva O.I., Samigulin T.I. Integration of modern microprocessor technology of a distributed control system with AIS algorithms / Shiryaeva O.I., Samigulin T.I. // Bulletin of NTU "KhPI". Series: Informatics and modeling. - Kharkov: NTU "KhPI". - 2021. - No. 1 (5). - 56-69s.

18. Samigulin T.I., Shiryaeva O.I. Development of an optimal control system for a complex technological process based on metaheuristic algorithms for swarm intelligence and Honeywell equipment. Herald of the KBTU. – 2021. – Issue. No. 1 (56). - S. 150-156.