CREATION OF INTELLECTUAL CONTROL SYSTEMS USING QUANTUM ALGORITHMS

Yakubova Noilakhon Sobirjonovna
Tashkent State Technical University
E-mail: noila.yakubova@gmail.ru
Ubaydulloyev Farrux Barakayevich
Tashkent State Technical University
Nasrullayeva Madina Sunnatilla qizi
Tashkent State Technical University
Tel: +998946853505

Abstract. This article studies the issues of synthesizing intelligent control systems in conditions of dynamic characteristics of technological processes, strong nonlinearity, and uncertainty of information arising from external and internal influences. Taking into account the variability of process parameters over time and the limited capabilities of classical control methods, effective models and algorithms aimed at improving the quality of control are developed. Particular attention is paid to optimizing the decision-making process, increasing the computational speed, and ensuring the system's adaptability using quantum algorithms and quantum computing principles. The results obtained show that the proposed approach is highly effective in ensuring stable and reliable control of technological objects in various operating modes.

Keywords: intelligent control systems, nonlinear technological processes, modeling, quantum algorithms, adaptive control, decision-making optimization, dynamic process modeling.

Annotatsiya. Ushbu maqolada texnologik jarayonlarning dinamik xususiyatlari, kuchli nochiziqliligi hamda tashqi va ichki ta'sirlar natijasida yuzaga keladigan ma'lumotlarning noaniqligi sharoitida intellektual boshqarish tizimlarini sintez qilish masalalari tadqiq etilgan. Jarayon parametrlarining vaqt bo'yicha o'zgaruvchanligi va klassik boshqarish usullarining cheklangan imkoniyatlarini hisobga olgan holda, boshqarish sifatini oshirishga qaratilgan samarador modellar va algoritmlar ishlab chiqilgan. Bunda kvant algoritmlari va kvant hisoblash tamoyillaridan foydalangan holda qaror qabul qilish jarayonini optimallashtirish, hisoblash tezkorligini oshirish hamda tizimning moslashuvchanligini ta'minlashga alohida e'tibor qaratilgan. Olingan natijalar taklif etilgan yondashuv texnologik ob'ektlarning turli ish rejimlarida barqaror va ishonchli boshqarilishini ta'minlashda yuqori samaradorlikka ega ekanini ko'rsatadi.

ISSN 3030-3907

Kalit so‘zlar: intellektual boshqaruv tizimlari, nochiziqli texnologik jarayonlar, modellashtirish, kvant algoritmlari, moslashuvchan boshqaruv, qarorqabul qilishni optimallashtirish, dinamik jarayonlarni modellashtirish.

Аннотация. В данной статье исследуются вопросы синтеза интеллектуальных систем управления в условиях динамических характеристик технологических процессов, их выраженной нелинейности, а также неопределённости данных, возникающей под воздействием внутренних и внешних факторов. С учётом временной изменчивости параметров процесса и ограниченных возможностей классических методов управления разработаны эффективные модели и алгоритмы, направленные на повышение качества управления. Особое внимание уделено оптимизации процесса принятия решений, повышению вычислительной эффективности и обеспечению адаптивности системы на основе квантовых алгоритмов и принципов квантовых вычислений. Полученные результаты показывают, что предложенный подход обладает высокой эффективностью и обеспечивает устойчивое и надёжное управление технологическими объектами в различных режимах их функционирования.

Ключевые слова: интеллектуальные системы управления, нелинейные технологические процессы, моделирование, квантовые алгоритмы, адаптивное управление, оптимизация принятия решений, динамическое моделирование процессов.

INTRODUCTION.

The rapid development of modern industrial technologies has significantly increased the complexity of technological processes, particularly in terms of their dynamic behavior, strong nonlinear characteristics, and sensitivity to internal and external disturbances. In such environments, achieving high-quality and reliable control remains a challenging task, as process parameters often vary over time and available measurements are affected by uncertainty and noise. These factors substantially limit the effectiveness of classical control methods, which are typically designed under assumptions of linearity and precise system modeling [1,2].

Intelligent control systems have emerged as a promising alternative for addressing these challenges by incorporating adaptive, learning-based, and decision-oriented mechanisms into the control structure. However, the synthesis of intelligent control systems for nonlinear and uncertain technological processes requires advanced modeling and optimization techniques capable of handling high-dimensional data, complex interactions, and real-time decision-making

ISSN 3030-3907

requirements [3]. Conventional computational approaches often face limitations in terms of processing speed and scalability when applied to such problems.

Recent advances in quantum computing and quantum-inspired algorithms have opened new opportunities for improving the performance of intelligent control systems [4]. By exploiting the principles of quantum superposition, parallelism, and probabilistic computation, quantum algorithms offer the potential to accelerate optimization and decision-making processes that are computationally intensive for classical methods. This makes them particularly suitable for real-time control applications operating under dynamic and uncertain conditions.

In this context, the present study focuses on the synthesis of intelligent control systems that explicitly account for the nonlinear dynamics and uncertainty inherent in technological processes [5,6]. Effective models and algorithms are developed by integrating quantum algorithms into the control framework, with particular emphasis on enhancing decision-making efficiency, computational speed, and system adaptability. The proposed approach is evaluated across various operating modes, demonstrating its capability to ensure stable and reliable control performance under changing process conditions [7].

RESEARCH METHODS AND THE RECEIVED RESULTS

In the design of intelligent information and communication systems, several critical challenges arise due to the structural complexity of the systems, heterogeneity of hardware components, uncertainty in operational requirements, variability of external conditions, and the presence of multiple interacting factors[8,9]. These challenges complicate the system design process and limit the effectiveness of conventional control approaches. Therefore, the selection of appropriate network function structures and the determination of optimal weight parameters play a crucial role in the synthesis of intelligent control systems, particularly when based on the principles of quantum computing theory [10].

The application of quantum computing algorithms in process control enables high-speed solutions to numerous classical optimization and decision-making problems that are computationally complex or intractable using traditional methods. Moreover, quantum-based approaches provide new opportunities to obtain approximate or probabilistic solutions to problems that cannot be solved algorithmically within reasonable time constraints. As a result, quantum computing algorithms significantly enhance the adaptability, computational efficiency, and robustness of intelligent control systems operating under uncertain and dynamically changing conditions [11,12].

In the presence of uncertainties in the models, incomplete formalization of control decision-making processes, and situations where decision selection models

ISSN 3030-3907

are often expressed only at a qualitative level, effective control of complex technological objects can still be achieved. Such an approach enhances the robustness of the control system with respect to internal and external uncertainties, reduces subjectivity in decision-making, and improves the overall reliability of the system [13].

The formation of technological processes based on the proposed method makes it possible to represent control models of dynamic objects operating under uncertainty within a unified mathematical framework, enabling their systematic investigation and analysis. Moreover, this approach provides a solid theoretical basis for the development of efficient modeling and simulation algorithms, evaluation of object behavior under various operating modes, and synthesis of optimal control strategies [14,15].

In general, the algorithm for modeling information and communication systems can be represented by the following sequence:

$$M = \prec I, P, \Phi, X, Y, \Omega \succ,$$

where: I – is the model identifier; $P = P(x_1, x_2, ..., x_n)$ – is a unary logical predicate defined on the set X, $\Phi : X \to Y(XUY = Z)$ – represents a description expressing a set of properties of the modeled algorithm; $X = \{x_1, x_2, ..., x_n\}$ - denotes the input variables of the computational model; $Y = \{y_1, y_2, ..., y_n\}$ - denotes the output variables of the computational model; $Z = \{z_1, z_2, ..., z_n\}$ - is the set of variables; Ω- is the set of identifiers, X and Y is the domain of ordered pairs of identifiers and their corresponding values, which together define the application domain of the model.

In general, the algorithm for constructing a quantum fuzzy network is as follows:

1. **Normalization.** The intersection of relations $P_1,\ldots,P_k$, is determined using the following formula to obtain: $Q_1 = R_1 \cap R_2 \cap ... \cap R_k$.

2. For Q_1, according to the following algorithm, the set of non-dominated alternatives is determined. First, the inverse matrix Q_1^{-1} is defined as: $\mu_{Q_1^{-1}}(x,y) = \mu_{Q_1}(x,y)$.

3. Then, for each element of the matrix, the corresponding element of the matrix K_1 is subtracted.If the result is negative, it is replaced by zero, i.e.,: $\mu_{Q_1^0}(x,y) = \max\left(0, \mu_{Q_1^{-1}}(x,y) - \mu_{Q_1}(x,y)\right)$.

For the matrix Q_1^0, the maximum value $r(x_i), i = 1,2,...,n$ is determined for each row, where i=1,2,…,n. The obtained values are then subtracted from unity. As a result,

ISSN 3030-3907

$\mu_{Q_1^{НД}}(x_i)$ the membership degrees of the non-dominated alternatives are obtained: $\mu_{Q_1^{НД}}(x_i)=1-r(x_i), i=1,2,...,n$.

Thus, the set of non-dominated alternatives is represented as a fuzzy set whose elements $x_1, x_2,\ldots,x_n$ are characterized by their corresponding membership degrees $\mu_{Q_1^{НД}}(x_i)$

This fuzzy set can be expressed in the following form: $\mu_i(x_i)=\{\mu_1(x_1)/x_1, \mu_2(x_2)/x_2,..., \mu_n(x_n)/x_n\}$

3. For the set of non-dominated alternatives P, the main non-dominated relation P^{ND} is determined in the same manner [16,17]. The obtained membership functions: $\mu_{R^{НД}}(g_1), \mu_{R^{НД}}(g_2),...,\mu_{R^{НД}}(g_k)$ are ranked according to the criteria $l_1, l_2,...,l_k$ and are denoted accordingly. For each criterion, the corresponding weight coefficients are defined as follows:

$$t_i=\frac{l_i}{\sum_{j=1}^{k} l_j}, i=1,2,...,k$$

.

4. The elements of the matrix Q_2 are calculated using the following formula:

$$\mu_{Q_1}(x,y)=\sum_{m=1}^{k} t_m \mu_{R_m}(x,y)$$

.

5. The non-dominated set $Q_2^{НД}$ is determined using the algorithms described above:

$$\mu_{Q_2^{НД}}(x_i)=\left\{\mu_{Q_2^{НД}}(x_1)/x_1, \mu_{Q_2^{НД}}(x_2)/x_2,...,\mu_{Q_2^{НД}}(x_n)/x_n\right\}.$$

6. The final relation is constructed as the intersection $Q=Q_1^{НД}\cap Q_2^{НД}$:

$$Q=\left\{\frac{\min\left(\mu_{Q_1^{НД}}(x_1);\mu_{Q_2^{НД}}(x_1)\right)}{x_1},...,\frac{\min\left(\mu_{Q_1^{НД}}(x_n);\mu_{Q_2^{НД}}(x_n)\right)}{x_n}\right\}=\left\{\mu_Q(x_1)/x_1,...,\mu_Q(x_n)/x_n\right\}.$$

.

The alternatives with the maximum membership degree in the set Q are considered to be rationally selected. In the development of technological process control systems, particular attention is paid to the creation of highly efficient methods for information processing and control action generation. Eliminating such problems requires the development of process control models capable of operating under complex uncertainty conditions, taking into account changes in external environmental characteristics as well as stochastic and random disturbances. Therefore, it becomes necessary to develop a quantum fuzzy control model that enables effective process control under uncertainty [18,19].

In this context, the dynamics of a technological process control system can be represented in the form of state equations as follows:

ISSN 3030-3907

$$x_{k+1} = F(x_k, u_k), k = \overline{0, N}; \quad x_k \in X, u_k \in U,$$

where X- denotes the state space, U- represents the set of admissible control inputs, and F is the state transition function, which in the general case has a nonlinear form:

$$F : X \times U \to X.$$

For dynamic systems characterized by various types of uncertainty, the state transition function can be represented in the form of a quantum fuzzy relation as follows:

$$F : X \times U \times X \to [0,1].$$

In this case, all partially undefined coefficients and all variables influencing the process are represented through the membership function $\mu(x_{k+1}/x_k, u_k)$.

The proposed approach provides a unified mathematical framework for the synthesis of intelligent control systems operating under nonlinear dynamics and uncertainty. By incorporating quantum fuzzy relations and non-dominated decision-making mechanisms, the method reduces subjectivity in control decisions and improves robustness against internal and external disturbances. In addition, the use of weighted criteria and quantum-inspired aggregation enhances computational efficiency and system adaptability, ensuring stable and reliable control performance of complex technological processes across various operating conditions [20].

CONCLUSION. In this study, an intelligent control approach based on quantum algorithms was developed for modeling and controlling complex technological processes operating under nonlinear dynamics and uncertainty. The use of quantum algorithms in the selection and synthesis of mathematical control models proved to be effective in representing the structured relationships among system variables. This approach enhances the accuracy of decision-making, improves computational efficiency, and increases the adaptability of the control system. The obtained results demonstrate that the proposed method ensures stable and reliable control performance across various operating modes, making it a promising solution for advanced technological process control applications.

REFERENCES

1. Usmanov, K., Eshbobaev, J., & Yakubova, N. (2023). Modeling and Optimization of the Ammonium Solution Extraction Process. Engineering Proceedings, 56(1), 198.

2. Frank Tabakin, Bruno Juliб-Dнaz, ”QCMPI: A parallel environment for quantum computing”, Computer Physics Communications №180, p. 948. 2009.

ISSN 3030-3907

3. Сидиков, И. Х., Усманов, К. И., Якубова, Н. С., & Казахбаев, С. А. (2020). НЕЧЕТКОЕ СИНЕРГЕТИЧЕСКОЕ УПРАВЛЕНИЕ НЕЛИНЕЙНЫХ СИСТЕМ. Journal of Advances in Engineering Technology, (2), 16-19.
4. L.Lace. Enlarging gap between quantum and deterministic query complexities. Proceedings of Baltic DB&IS 2004, vol. 2, Riga, Latvia, pp. 81.-91. .
5. Sidikov, I. K., Usmanov, K. I., Yakubova, N. S., & Kazakhbaev, S. A. (2020). Fuzzy synergetic control of nonlinear systems. Journal of Advances in Engineering Technology,(2), 16-19.
6. Усманов, К. И., Сарболаев, Ф. Н., Исломова, Ф. К., & Якубова, Н. С. (2020). Адаптивно нечеткое синергетическое управление многомерных нелинейных динамических объектов. Universum: технические науки, (3-1 (72)), 24-28.
7. Litvintseva L. V., Ulyanov I.S., Ulyanov S. V., Ulyanov S. S. Quantum fuzzy inference for knowledge base design in robust intelligent controllers // Computer and Systems Sciences Intern. – 2007. – Vol. 46. – № 6. – Pp. 908-961.
8. Litvintseva L.V., Ulyanov S.S., Takahashi K. et all. Intelligent robust control design based on new types of computation. Pt 1 // New soft computing technology of KB-design of smart control simulation for nonlinear dynamic systems. – Milan: Note del Polo (Ricerca), Universita degli Studi di Milano, 2004. – Vol. 60..
9. Yakubova, N. S., & Abdurasulova, G. E. (2023). Study of fuzzy controllers in intelligent control systems based on quantum computing. Universum: technical sciences: electron. scientific magazine.
10. Venegas-Andraca S. E. Quantum Walks for Computer Scientists. Synthesis Lectures on Quantum Computing, Morgan Claypool, 2008, 133 p.
11. Metodi T. S., Faruque A. I., Chong F. T. Quantum Computing for Computer Architects. Synthesis Lectures on Computer Architecture, Morgan Clay-pool, 2011, 203 p.
12. Yakubova, N. S. (2023). Synthesis of the control system of complex dynamic objects based on quantum computing methods. Descendants of Muhammad al-Khorazmi. Scientific-practical and information-analytical journal.(2023-y.).
13. Cirac J.I., Zoller P., “Goals and opportunities in quantum simulation”, Nature Physics, 8 (2010), 264–266.
14. Yakubova, N. S. (2023). Application of quantum algorithms in the synthesis of dynamic objects. Chemical Technology. Control and Management, 6, 61-67.
15. S. Rastegar, R. Araújo, J. Sadati, and J. Mendes, “A novel robust control scheme for LTV systems using output integral discrete-time synergetic control theory,” Eur. J. Control, vol. 34, pp. 39–48, 2017, doi: 10.1016/j.ejcon.2016.12.006.

ISSN 3030-3907

16. Якубова, Н. С., & Абдурасулова, Г. Э. (2023). Исследование нечетких регуляторов в системах интеллектуального управления на основе квантовых вычислений. Universum: технические науки, (3-1 (108)), 22-25.
17. Usmanov, K. I. (2022). SYNERGISTIC INTELLIGENT CONTROL OF NONLINEAR DYNAMIC OBJECTS. Journal of Advances in Engineering Technology, (1), 10-13.
18. Sidikov, I. X., Usmanov, K. I., Yakubova, N. S., & Kazaxbayev, S. A. (2020). Nechetkoye sinergeticheskoye upravleniye neli-neynix sistem. Journal of Advances in Engineering Technology, 2.
19. Ablayev F., Ablayev M. On the concept of cryptographic quantum hashing. Laser Phys. Lett., 2015, vol. 12, no. 12, art. 125204, pp. 1–5. doi: 10.1088/1612-2011/12/12/125204.
20. Usmanov, K. I., Islamova, F. K., & Yakubova, N. S. (2023). DEVELOPMENT OF A MATHEMATICAL MODEL OF THE DIESEL FUEL HYDROTREATMENT PROCESS. Universum: technical sciences: electron. scientific journal, 2, 107.

ISSN 3030-3907