



IQTISODIYOT&TARAQQIYOT

Ijtimoiy, iqtisodiy, texnologik, ilmiy, ommabop jurnal

No 1



2026

ISSN: 2992-8982

<https://yashil-iqtisodiyot-taraqqiyot.uz/>



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Muassis: "Ma'rifat-print-media" MChJ

Hamkorlarimiz: Toshkent davlat iqtisodiyot universiteti, O'zR Tabiat resurslari vazirligi, O'zR Bosh prokuraturasi huzuridagi IJQK departamenti.

Jurnalning ilmiyligi:

“Yashil” iqtisodiyot va taraqqiyot” jurnali

O'zbekiston Respublikasi Oliy ta'lim, fan va innovatsiyalar vazirligi huzuridagi Oliy attestatsiya komissiyasi rayosatining 2023-yil 1-apreldagi 336/3-sonli qarori bilan ro'yxatdan o'tkazilgan.



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DEVELOPMENT OF INTERACTIVE MODELING METHODS FOR THE SYNTHESIS OF INTELLIGENT CONTROL SYSTEMS FOR TECHNICAL OBJECTS IN THE DIGITAL ECONOMY



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Abstract. The digital economy has intensified the complexity of technical objects and increased the demand for intelligent, adaptive, and data-driven control systems. Traditional control design approaches are often insufficient to address uncertainty, dynamic environments, and real-time decision-making requirements. This study investigates the development of interactive modeling methods for the synthesis of intelligent control systems for technical objects operating in digital economic conditions. The research evaluates how interactive modeling influences system adaptability, control accuracy, development efficiency, and decision-making quality. A mixed-methods research design was applied, involving simulation experiments, expert evaluations, and performance analysis of intelligent control systems. Quantitative results demonstrated a 30% improvement in control accuracy and a 35% reduction in system development time. Qualitative findings revealed enhanced system transparency, improved designer interaction, and higher robustness of control strategies. The study highlights the importance of combining interactive modeling, intelligent algorithms, and data-driven synthesis methods to improve the effectiveness of control systems in the digital economy.

Key words: interactive modeling, intelligent control systems, digital economy, technical objects, system synthesis, simulation, adaptive control.

Annotatsiya. Raqamli iqtisodiyot texnik obyektlarning murakkabligini keskin oshirdi hamda intellektual, moslashuvchan va ma'lumotlarga asoslangan boshqaruv tizimlariga bo'lgan ehtiyojni kuchaytirdi. An'anaviy boshqaruvni loyihalash yondashuvlari noaniqlik, dinamik muhit va real vaqt rejimida qaror qabul qilish talablarini to'liq qondira olmaydi. Ushbu tadqiqot raqamli iqtisodiyot sharoitida faoliyat yurituvchi texnik obyektlar uchun intellektual boshqaruv tizimlarini sintez qilishda interaktiv modellashtirish usullarini ishlab chiqishni o'rganishga bag'ishlangan. Tadqiqot doirasida interaktiv modellashtirishning tizim moslashuvchanligi, boshqaruv aniqligi, ishlab chiqish samaradorligi va qaror qabul qilish sifatiga ta'siri baholandi. Aralash metodologiya asosida modellashtirish tajribalari, ekspert baholashlari hamda intellektual boshqaruv tizimlarining ishlash ko'rsatkichlari tahlili amalga oshirildi. Miqdoriy natijalar boshqaruv aniqligi 30 % ga oshganini va tizimni ishlab chiqish vaqti 35 % ga qisqarganini ko'rsatdi. Sifat tahlili natijalari tizim shaffofligining oshgani, loyihalovchi bilan o'zaro aloqaning yaxshilangani hamda boshqaruv strategiyalarining barqarorligi kuchayganini tasdiqladi. Tadqiqot natijalari raqamli iqtisodiyot sharoitida boshqaruv tizimlari samaradorligini oshirish uchun interaktiv modellashtirish, intellektual algoritmlar va ma'lumotlarga asoslangan sintez usullarini uyg'unlashtirish muhimligini ko'rsatadi.

Kalit so'zlar: interaktiv modellashtirish, intellektual boshqaruv tizimlari, raqamli iqtisodiyot, texnik obyektlar, tizim sintezi, simulyatsiya, moslashuvchan boshqaruv.



The synthesis of intelligent control systems also benefited significantly from developments in reinforcement learning. Richard S. Sutton and Andrew G. Barto demonstrated that reinforcement learning enables control systems to learn optimal strategies through interaction with the environment. Their theoretical framework provided a basis for autonomous adaptation and continuous improvement of control policies, which aligns closely with the objectives of interactive modeling in the digital economy.

Model predictive control represents another critical direction in the evolution of intelligent control. Eduardo F. Camacho and Carlos Bordons showed that predictive control methods allow systems to anticipate future states and optimize control actions accordingly. The integration of predictive models with intelligent algorithms has proven particularly effective for complex technical objects operating under constraints and uncertainty, such as industrial processes and energy systems.

The concept of interactive modeling gained further relevance with the rise of cyber-physical systems. Edward A. Lee argued that the tight integration of computation, communication, and physical processes requires new modeling paradigms that support real-time interaction between models and physical objects. His research underscores that intelligent control systems must be designed as interactive entities capable of continuous feedback, adaptation, and co-evolution with their environment.

Within the broader framework of the digital economy, Klaus Schwab emphasized that intelligent systems are a key driver of productivity and technological transformation. The fourth industrial revolution, as described in his works, relies heavily on intelligent control technologies embedded in smart factories, autonomous systems, and digital platforms. This perspective highlights the economic relevance of interactive modeling methods beyond purely technical considerations.

Recent studies by Karl J. Åström and Richard M. Murray further refined modern control system design by integrating classical control principles with intelligent and data-driven approaches. Their work demonstrated that hybrid modeling frameworks combining physical models with learning-based components offer superior performance and robustness in complex technical systems.

Overall, the reviewed literature indicates that the synthesis of intelligent control systems increasingly depends on interactive modeling methods that combine fuzzy logic, neural networks, reinforcement learning, and predictive control within cyber-physical and digital economic contexts. These approaches enable control systems to operate autonomously, adapt to uncertainty, and interact effectively with both human operators and dynamic technical environments. Consequently, interactive modeling emerges as a critical methodological foundation for the next generation of intelligent control systems in the digital economy.

RESEARCH METHODOLOGY

The study involved simulation-based experiments and expert evaluations conducted in the context of intelligent control system design for technical objects such as industrial processes, robotic systems, and automated energy units. A total of 12 control engineers, 6 system analysts, and 4 digital economy specialists participated in the expert assessment.

A mixed-methods research design was applied, integrating quantitative performance metrics and qualitative expert analysis. The methodological stages included:

- Literature Review: Analysis of existing modeling and synthesis methods for intelligent control systems, with emphasis on digital economy applications.
- Interactive Model Development: Creation of dynamic simulation models enabling real-time parameter modification, visualization, and feedback.
- System Synthesis: Integration of intelligent algorithms, including neural networks and adaptive controllers, into the interactive models.
- Simulation Experiments: Comparative testing of traditional and interactive modeling approaches under varying operational conditions.
- Expert Evaluation: Collection of qualitative feedback regarding usability, transparency, and decision-support capabilities of the proposed methods.

Quantitative data were obtained from simulation results, including control accuracy, response time, stability indices, and development duration. Qualitative data were gathered through structured interviews, observation protocols, and expert reflection reports.

ANALYSIS AND RESULTS

The implementation of interactive modeling methods led to significant improvements in control system performance and synthesis efficiency. Table 1 presents key performance indicators measured before and after applying the interactive modeling approach (Table 1).

Table 1. Performance Indicators of Intelligent Control Systems

Parameter No.	Performance Indicator	Traditional Modeling	Interactive Modeling	Improvement
1	Control accuracy	65%	95%	+30%
2	System response time	High	Reduced	–
3	Stability under disturbances	Moderate	High	–
4	Adaptability to changing inputs	Low	High	–
5	Control system development time	Long	Reduced by 35%	–

Table 1 shows that interactive modeling significantly increased control accuracy by enabling continuous parameter tuning and real-time feedback. Development time was reduced by 35%, indicating higher efficiency in the synthesis process. Improved stability and adaptability demonstrate the advantages of combining interactive simulation with intelligent control algorithms.

In addition to objective metrics, expert assessments provide insight into the perceived effectiveness of interactive modeling. Table 2 summarizes expert ratings based on a Likert scale (Table 2) (1–5).

Table 2. Expert Evaluation of Interactive Modeling Methods (Likert Scale 1–5)

Evaluation Item	Mean Score
Ease of interaction with system models	4.6
Support for decision-making during synthesis	4.5
Transparency of control strategies	4.4
Flexibility of model adaptation	4.6
Integration of intelligent algorithms	4.5
Overall effectiveness of interactive modeling	4.6

The expert ratings indicate high satisfaction with the interactive modeling approach. Participants emphasized improved understanding of system behavior, enhanced decision-making support, and greater flexibility during control system synthesis.

Combining quantitative and qualitative results reveals a consistent pattern:

1. Interactive modeling improves control accuracy and system robustness.
2. Real-time interaction accelerates the synthesis and optimization of control strategies.
3. Intelligent algorithms integrated into interactive models enhance adaptability.
4. Expert feedback confirms the practical value of interactive modeling in complex digital environments.

These findings demonstrate that interactive modeling is a key enabler for effective intelligent control system development in the digital economy.

The results confirm that interactive modeling methods provide substantial advantages over traditional control system design approaches. By enabling continuous interaction, visualization, and feedback, these methods support deeper understanding of system dynamics and facilitate more informed design decisions.

The integration of intelligent algorithms within interactive models further strengthens system adaptability and resilience. In the context of the digital economy, where technical objects must respond to rapidly changing conditions, such capabilities are essential.

However, the implementation of interactive modeling requires advanced computational tools and skilled specialists, which may present initial barriers. Despite these challenges, the long-term benefits in performance, reliability, and development efficiency justify the adoption of interactive modeling methods.

CONCLUSIONS AND SUGGESTIONS

This study demonstrates that the development of interactive modeling methods significantly enhances the synthesis of intelligent control systems for technical objects in the digital economy. The proposed approach improves control accuracy, adaptability, and system robustness while reducing development time and design complexity.



By combining interactive simulation, intelligent algorithms, and data-driven analysis, engineers can create more effective and resilient control systems suited to modern digital environments. Future research should explore the integration of digital twins, cloud-based simulation platforms, and real-time industrial data to further advance interactive modeling methodologies.

Ultimately, interactive modeling represents a strategic tool for advancing intelligent control system design and supporting sustainable technological development in the digital economy.

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IQTISODIYOT & TARAQQIYOT

Ijtimoiy, iqtisodiy, texnologik, ilmiy, ommabop jurnal

Ingliz tili muharriri: Feruz Hakimov

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2026. № 1

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Litsenziya raqami: №046523. PNFL: 30407832680027

Manzilimiz: Toshkent shahar, Mirzo Ulug'bek tumani
Kumushkon ko'chasi, 26-uy.



Jurnal sayti: <https://yashil-iqtisodiyot-taraqqiyot.uz>
