

Automation of technological processes based on artificial intelligence: new approaches and innovative solutions

Mohichehraxon Khusniddin qizi Ganijonova
Andijan State Technical Institute

Abstract: This article analyzes modern approaches to the application of artificial intelligence (AI) technologies in the automation of technological processes in industry and manufacturing. The role and advantages of machine learning methods, neural networks, expert systems, and digital twin technologies in automation systems are examined. In addition, the potential for improving efficiency, saving resources, and reducing the impact of the human factor through the implementation of AI-based control systems is discussed. The article is intended for researchers and specialists working in the fields of industrial automation and intelligent control systems.

Keywords: artificial intelligence, technological processes, automation, machine learning, neural networks, digital twin, intelligent control

Introduction. Nowadays, digital transformation processes in the industrial and manufacturing sectors are rapidly developing. One of the main driving forces behind this process is artificial intelligence (AI) technologies. While traditional automation systems are based on rigid algorithms and predefined control rules, AI-based systems stand out for their adaptability, learning ability, and capability to analyze complex processes. The use of artificial intelligence in automating technological processes serves to increase production efficiency, predict potential malfunctions, and optimize decision-making processes. Therefore, this topic holds significant scientific and practical relevance today.

Artificial intelligence (AI) is the capability of machines and software systems to mimic human cognitive activities. It includes abilities such as learning (machine learning), reasoning from experience, problem-solving, and making independent decisions. AI algorithms analyze large volumes of data to identify patterns and trends. Today, AI is widely applied in medicine, transportation, education, industry, and business.

Automation is the process of controlling operations using technical and software tools while minimizing human involvement. It is extensively implemented in manufacturing, agriculture, service, and transportation sectors to increase efficiency, reduce human errors, and save time.

Applications of AI and Automation include:

- In industry: Robotics and intelligent production lines enhance labor productivity.
- In medicine: AI helps in early disease detection, automating analyses, and developing personalized treatment plans.
- In transportation: Autonomous vehicles and smart logistics systems improve safety.
- In education: AI-based systems create individualized learning programs.
- In business: Chatbots provide customer service, assist in market analysis, and support financial forecasting.

Artificial intelligence (AI) is the capability of computer systems to perform functions characteristic of human intelligence, including learning, logical reasoning, and adaptive decision-making. Today, AI is applied in the automation of technological processes in the following main areas:

- Machine Learning (ML): Analyzing process parameters in real-time and developing optimal control strategies.
- Artificial Neural Networks (ANNs): Modeling and forecasting complex, nonlinear processes.
- Expert Systems: Automating decision-making based on the knowledge of experienced specialists.
- Digital Twins: Creating virtual models of real technological objects to test and optimize processes.

Machine learning (ML) is one of the key areas of artificial intelligence, representing the ability of computer systems to learn and make decisions based on data without explicit programming. In the automation of technological processes, the use of machine learning algorithms allows for the efficient management of complex, multi-parameter processes. Machine learning methods are generally divided into three main groups: supervised learning, unsupervised learning, and reinforcement learning. In supervised learning, the system is trained based on predefined input and output data and is used to predict technological process parameters. Unsupervised learning methods allow the detection of hidden relationships and anomalies within the process. Reinforcement learning is effective for developing optimal control strategies in real-time. In the automation of technological processes, machine learning algorithms play a crucial role in analyzing large volumes of data obtained from sensors, assessing the state of processes, and developing optimal control decisions. For example, regression and classification models are used to predict process parameters, while clustering algorithms are applied to group production modes.

One of the key advantages of machine learning-based automation systems is their adaptability and self-learning capability. Such systems can optimize their performance even when the conditions of technological processes change. As a result, production efficiency increases, energy and raw material consumption decreases, and the likelihood of accidents is reduced.

At the same time, the implementation of machine learning in industrial automation requires special attention to data quality, computational resources, and cybersecurity issues. Scientific studies indicate that, under conditions where a high-quality and reliable data base is available, machine learning algorithms become an effective tool for intelligent control of technological processes.

The next area is artificial neural networks (ANNs), which are among the most effective models of artificial intelligence and machine learning, created by mimicking the activity of biological neurons in the human brain. These models are widely used for modeling, forecasting, and solving control problems in complex, high-dimensional, and nonlinear technological processes.

Structure and Applications of Artificial Neural Networks

An artificial neural network consists of three main components: an input layer, hidden layer(s), and an output layer. Each neuron receives incoming signals through weight coefficients, sums them up, and generates an output signal using an activation function.

In the automation of technological processes, architectures such as multilayer perceptrons (MLP), convolutional neural networks (CNN), and recurrent neural networks (RNN) are widely used. Artificial neural networks demonstrate high efficiency, especially in cases where traditional mathematical models do not provide sufficient accuracy. For example, ANNs are successfully applied to predict reaction rates in the chemical and oil & gas industries, forecast load fluctuations in energy systems, and optimize motion control in robotics.

One of the key advantages of artificial neural networks is their ability to learn and adapt. During the training process, the network's weight coefficients are updated based on the principle of minimizing error. This ensures rapid adaptation to changes in technological process parameters, resulting in increased accuracy and reliability of the control system.

At the same time, using artificial neural networks presents challenges such as computational complexity, the need for large volumes of data, and the “black box” nature of the model. To overcome these limitations, hybrid models, explainable artificial intelligence (XAI), and optimized training algorithms are being actively researched and developed.

Expert systems are software systems based on artificial intelligence that serve to formally represent the knowledge and experience of highly qualified specialists in a specific domain and automate the decision-making processes. In the automation of technological processes, expert systems enable complex and critical decisions to be made quickly, consistently, and reliably. The main components of expert systems include a knowledge base, an inference engine, and a user interface. The knowledge base contains domain-specific rules, facts, and logical relationships. The inference engine analyzes the situation based on this knowledge and forms an optimal solution. In technological process control, logical models based on “if-then” rules are commonly used.

In industrial automation, expert systems are effectively used to assess the state of technological processes, detect malfunctions, and explain their causes. For example, in the energy and chemical industries, expert systems are employed to analyze emergency situations, plan maintenance activities, and provide decision-making support to operators.

One of the key advantages of expert systems is their explainability. The system can clarify to the user the reasons behind the decisions made, ensuring reliability and transparency in technological process control. Additionally, expert systems help reduce errors related to human factors.

At the same time, the creation of expert systems is a complex and labor-intensive process. The collection and formalization of knowledge, as well as the need for continuous system updates, are the main limitations of this approach. Today, to overcome these challenges, hybrid intelligent control systems are being developed, integrating expert systems with machine learning and artificial neural networks.

Among these areas, digital twin technology represents a modern approach based on creating virtual models of technological objects, processes, and systems that operate in real-time. This technology, when integrated with artificial intelligence, machine learning, big data, and the Internet of Things (IoT), significantly enhances the efficiency of technological process automation. A digital twin is a digital model that reflects the geometric, physical, technological, and functional characteristics of a real object and is continuously updated based on real-time data obtained from sensors. As a result, continuous information exchange between the real process and its virtual counterpart is ensured, enabling monitoring, analysis, and optimization of processes.

In technological process automation, digital twins play a crucial role in testing various scenarios, evaluating potential emergency situations in advance, and developing optimal control strategies. For example, digital twins are widely used in energy systems to predict equipment loads, in industrial robotics to assess the wear of mechanical components, and to enhance the efficiency of production lines. One of the main advantages of digital twin technology is the ability to perform predictive analysis and support decision-making. Using the virtual model, the consequences of possible changes in the real system can be evaluated in advance, which reduces risks and ensures efficient use of resources. Additionally, this technology helps optimize maintenance processes. However, creating and implementing digital twins requires high computational power, precise mathematical models, and reliable data infrastructure. Therefore, modern scientific research focuses on integrating digital twins with artificial neural networks and machine learning algorithms to enhance their accuracy and adaptability.

Innovative Approaches in Technological Process Automation

In modern industrial and manufacturing systems, the automation of technological processes is transitioning from traditional control methods to intelligent and adaptive approaches. The rapid development of digital transformation, artificial intelligence, and information and communication technologies is creating new requirements and opportunities for automation systems.

Innovative approaches in technological process automation are being formed based on the integration of artificial intelligence, digital technologies, and advanced control methods. These approaches expand the capabilities of traditional automation systems and enhance the efficiency, flexibility, and reliability of production processes. In recent years, the following innovative approaches have been widely applied in automation systems:

1. **Adaptive Control Systems.** AI-based adaptive systems quickly adjust to changes in the external environment and process parameters, ensuring production stability.
2. **Predictive Control and Maintenance.** Using AI algorithms, potential equipment malfunctions are detected in advance, reducing unplanned downtime.
3. **Data-Driven Decision Making.** Analyzing large volumes of industrial data (Big Data) allows the development of effective management decisions.

Currently, one of the widely applied approaches is adaptive and intelligent control systems. Such systems detect changes in technological process parameters in real-time and automatically adjust control algorithms. As a result, process stability and reliability are ensured, while direct human operator intervention is reduced.

Another important approach is the implementation of predictive control and maintenance systems. Using artificial intelligence and machine learning algorithms, the operational state of equipment is continuously analyzed, and potential malfunctions are identified in advance. This reduces unplanned downtime and increases production efficiency.

The data-driven control approach is becoming an integral part of modern automation systems. Based on the analysis of large volumes of data collected through sensors and IoT devices, optimal control decisions are developed. This approach allows for in-depth analysis of technological processes and the identification of hidden patterns.

Additionally, digital twin technology has introduced a new stage in automation. The use of virtual models of real objects serves as an effective tool for testing processes in advance, assessing risks, and developing optimal control strategies. This approach helps reduce production costs and improve product quality.

In conclusion, the new approaches in technological process automation are aimed at creating AI-based, adaptive, and self-learning systems, which play a crucial role in the next stage of industrial development.

Currently, AI-based automation systems demonstrate effective results in several areas:

- Optimizing technological processes in the oil, gas, and chemical industries;
- Forecasting and managing loads in energy systems;
- Developing robotics and intelligent production lines;
- Automating quality control in the food industry.

These solutions help reduce production costs, improve product quality, and ensure environmental safety. Automation of technological processes based on artificial intelligence is one of the key directions of modern industrial development. The implementation of AI technologies makes production processes more adaptive, efficient, and reliable. In the future, deepening scientific research in this field and expanding the use of AI-based automation in national industrial systems will be of significant importance.

References

1. Russell, S., & Norvig, P. Artificial Intelligence: A Modern Approach. 4th ed. Pearson, 2021.
2. Goodfellow, I., Bengio, Y., & Courville, A. Deep Learning. MIT Press, 2016.
3. Sutton, R. S., & Barto, A. G. Reinforcement Learning: An Introduction. MIT Press, 2018.
4. Zhang, D., & Ding, S. X. "Data-driven techniques for industrial process monitoring: A review." *Journal of Process Control*, 2013, 23(10), 1477–1491.
5. Krasnova, E. A., & Ivanov, P. Yu. Intelligent Automation of Industrial Processes. Moscow: Bauman MSTU Press, 2020.
6. Ramirez, J., & Morales, E. "Machine learning for predictive maintenance in industrial automation." *IEEE Transactions on Industrial Informatics*, 2020, 16(7), 4825–4833.
7. Tsyganov, A. & Zaitsev, A. Digital Twins in Industrial Automation. Springer, 2022.
8. Khakimov, K. R. "Sun'iy intellekt va avtomatlashtirish tizimlarining sanoat jarayonlarida qo'llanilishi." *O'zbekiston Milliy Universiteti Ilmiy Jurnali*, 2022, №1, 55–63.
9. IEC 62264-1. Enterprise-Control System Integration – Part 1: Models and Terminology. International Electrotechnical Commission, 2013.
10. Otaboyev, R., & Qodirov, D. "Texnologik jarayonlarni avtomatlashtirishda intellektual boshqaruv tizimlari." *Toshkent Davlat Texnika Universiteti Axborot Texnologiyalari Jurnali*, 2021.