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MODERN METHODS FOR AUTOMATING TECHNOLOGICAL PROCESSES IN THE FOOD INDUSTRY

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Abstract. This article examines modern methods and technologies for automating technological processes in the food industry, focusing on improving production efficiency, product quality, food safety, and resource utilization. Particular attention is paid to the application of programmable logic controllers (PLCs), supervisory control and data acquisition (SCADA) systems, industrial Internet of Things (IIoT), artificial intelligence (AI), machine learning, robotics, and digital twin technologies. The study analyzes the theoretical foundations of industrial automation, identifies the main challenges associated with implementing intelligent control systems, and proposes an integrated framework for improving food production management. The findings indicate that combining traditional automation with advanced digital technologies can enhance process stability, facilitate real-time monitoring, reduce operational inefficiencies, and support sustainable production. The article also discusses the economic and technological implications of automation and provides recommendations for the gradual implementation of intelligent manufacturing systems in food processing enterprises.

Keywords: food industry, technological processes, industrial automation, artificial intelligence, programmable logic controllers, SCADA, Internet of Things, robotics, digital transformation, intelligent manufacturing, food safety, production efficiency.

Introduction.

The food industry is one of the most strategically important sectors of the global economy, ensuring food security, supporting agricultural development, creating employment opportunities, and contributing to economic growth. The increasing demand for safe, high-quality, affordable, and environmentally sustainable food products has intensified the need for technological modernization and innovative production management. Modern food manufacturing enterprises operate under conditions characterized by changing consumer preferences, strict food safety requirements, rising energy costs, increasing competition, and the need to minimize production losses. These challenges require the implementation of advanced technological solutions capable of ensuring process reliability, operational efficiency, and consistent product quality. Industrial automation has become an essential component of modern food production. It involves the application of control systems, sensors, computing technologies, and automated equipment to monitor and regulate manufacturing operations with reduced dependence on continuous manual intervention.

Traditionally, food processing enterprises have relied on mechanical automation, electromechanical control systems, and conventional industrial controllers. However, the development

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of digital technologies has significantly expanded the capabilities of industrial automation. The integration of artificial intelligence, machine learning, the industrial Internet of Things, cloud computing, robotics, and digital twins has created new opportunities for intelligent monitoring, predictive maintenance, adaptive control, and production optimization.

In particular, modern automation technologies enable food manufacturers to control critical parameters such as temperature, pressure, humidity, processing time, flow rate, acidity, and product composition. For example, automated temperature control systems are widely used in pasteurization, sterilization, refrigeration, baking, and drying processes. Similarly, intelligent sensors and machine vision systems can detect product defects, monitor packaging quality, and identify deviations from established technological standards. Despite these advantages, the implementation of advanced automation systems presents significant challenges, including high initial investment costs, insufficient digital infrastructure, cybersecurity risks, limited technical expertise, and difficulties integrating modern technologies with existing production equipment.

Therefore, the scientific investigation of modern methods for automating technological processes in the food industry remains an important research direction.

The aim of this study is to investigate modern automation methods used in food processing enterprises, evaluate their technological and economic advantages, and develop an integrated framework for improving the efficiency, safety, and reliability of food production systems.

The main objectives of the study are: To examine the theoretical foundations of technological process automation in the food industry. To identify modern automation technologies and their industrial applications. To analyze the role of intelligent control systems in improving food production efficiency. To evaluate the potential benefits and limitations of digital automation technologies. To propose an integrated model for implementing intelligent automation in food manufacturing enterprises. Research object technological processes and automated production systems in food manufacturing enterprises. Research subject methods, technologies, and organizational mechanisms for automating and optimizing food production processes.

Literature review. The automation of technological processes in the food industry has attracted considerable attention from researchers specializing in industrial engineering, control systems, food technology, robotics, and digital manufacturing. The theoretical foundations of industrial automation are closely associated with the development of automatic control theory, cyber-physical systems, and intelligent manufacturing concepts. Kagermann, Wahlster, and Helbig (2013) introduced strategic recommendations for implementing Industry 4.0, emphasizing the integration of information technologies, physical production systems, and intelligent communication networks. Their research established a conceptual basis for the digital transformation of manufacturing enterprises.

Lee, Bagheri, and Kao (2015) developed a cyber-physical systems architecture for Industry 4.0-based manufacturing. Their approach highlights the importance of real-time data collection, intelligent analysis, and interconnected production equipment.

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Kusiak (2018) examined the development of smart manufacturing systems and emphasized the role of data-driven decision-making in improving operational efficiency and manufacturing flexibility. Wuest et al. (2016) investigated machine learning applications in manufacturing, identifying opportunities for quality control, process optimization, fault detection, and predictive maintenance. In food processing, automation has particular importance because production operations frequently involve biological materials, complex physicochemical transformations, and strict sanitary requirements. Sun (2016) discussed the development of computer vision and intelligent processing technologies for food quality evaluation. These technologies provide opportunities for detecting defects, assessing product appearance, and improving inspection consistency. Brosnan and Sun (2004) examined computer vision applications in food quality evaluation and highlighted the potential of automated inspection technologies to support objective quality assessment. Tao et al. (2018) investigated digital twin technologies and their applications in monitoring equipment conditions and supporting predictive maintenance. Although their research focuses on general industrial systems, its methodological principles are relevant to food processing equipment. The literature demonstrates that modern automation is increasingly shifting from isolated machine control toward interconnected, data-driven production management.

However, several research gaps remain. First, many automation solutions are developed for specific technological operations without sufficient consideration of enterprise-wide integration. Second, the economic effectiveness of advanced automation technologies depends strongly on production scale, process characteristics, and the existing technical infrastructure. Third, food safety requirements introduce additional constraints that distinguish food manufacturing from other industrial sectors. Consequently, further research is needed to develop integrated automation frameworks that combine technological efficiency, food safety, economic feasibility, and environmental sustainability.

Research methodology. This study adopts a theoretical and analytical research approach based on a review of scientific literature, comparative analysis of automation technologies, systems analysis, and conceptual modeling. The methodological framework consists of four main components: technological process analysis, automation system classification, performance evaluation, and integrated system design.

Systems analysis. The systems approach is used to investigate the relationships between production equipment, technological parameters, control algorithms, information flows, and management decisions.

Food production is considered an interconnected system in which changes in one technological parameter may influence product quality, energy consumption, processing time, and operational safety.

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Comparative analysis. A comparative approach is applied to evaluate traditional and modern automation technologies according to their functionality, adaptability, data processing capabilities, and implementation requirements.

Mathematical modeling. Mathematical modeling is used to describe technological control processes and identify indicators for evaluating automation performance.

The general dynamic behavior of a technological process can be expressed as:

$$\frac{dx(t)}{dt}=f(x(t),u(t),d(t))$$

where:

−x(t) represents the state variables of the technological process;

−u(t) represents control inputs;

−d(t) represents external disturbances;

−f describes the dynamic relationships within the system.

The output variables are represented by:

$$y(t)=g(x(t),u(t))$$

where y(t) represents measurable process outputs.

These equations provide a general mathematical foundation for developing automated control systems.

Performance evaluation. The effectiveness of automation technologies is evaluated using indicators such as production productivity, product quality, energy efficiency, equipment availability, processing accuracy, and operational costs. This article does not present results from a newly conducted industrial experiment. Its findings are based on theoretical analysis, published research, and illustrative engineering calculations.

Results and discussion. The development of modern food manufacturing is increasingly associated with the integration of automated control systems, intelligent sensors, and digital technologies.

Automation methods can be divided into several major categories.

Table 1. Modern automation technologies and their applications in the food industry

Automation technology	**Main application**	**Potential benefits**
Programmable logic controllers (PLC)	Control of processing equipment and production lines	Reliable sequential and continuous control
SCADA systems	Real-time monitoring and supervisory control	Improved process visibility and fault identification
Industrial Internet of Things	Sensor connectivity and data collection	Continuous monitoring and data availability
Artificial intelligence	Prediction, optimization, and decision support	Adaptive process management

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Automation technology	Main application	Potential benefits
Machine learning	Quality prediction and equipment diagnostics	Earlier detection of deviations
Industrial robotics	Sorting, packaging, palletizing	Consistent handling and reduced repetitive labor
Computer vision	Visual quality inspection	Automated detection of visible defects
Digital twins	Virtual process representation and simulation	Scenario analysis and operational optimization
Advanced process control	Multivariable process regulation	Improved control under process constraints

The application of these technologies depends on the characteristics of the production process and the economic capabilities of the enterprise.

Programmable logic controllers in food processing. Programmable logic controllers are widely used in industrial automation because of their reliability, flexibility, and ability to operate in demanding production environments. PLCs execute programmed control algorithms using signals received from sensors and other industrial devices. In food manufacturing, PLCs are commonly applied to control conveyor systems, filling machines, mixers, ovens, refrigeration units, and packaging equipment. A typical PLC-based control system consists of input devices, a central processing unit, output modules, communication interfaces, and operator interfaces. For example, in an automated liquid filling system, sensors detect the position of containers, while the PLC controls valves, pumps, and conveyor movement according to the programmed production sequence. The main advantages of PLC-based automation include reliable operation, repeatable control actions, reduced dependence on manual switching, and integration with industrial communication networks. However, PLCs primarily execute predefined control logic. Advanced predictive or adaptive functions generally require additional algorithms, computing resources, or integration with higher-level analytical systems.

SCADA systems and real-time monitoring. Supervisory Control and Data Acquisition systems provide centralized monitoring and supervisory control of industrial processes. In food manufacturing enterprises, SCADA systems collect information from production equipment and display technological parameters through graphical interfaces. These systems allow operators to monitor temperature, pressure, flow rates, equipment status, alarm conditions, and other production indicators. For example, a dairy processing enterprise may use SCADA to monitor pasteurization temperatures, product flow rates, storage tank levels, and cleaning-in-place operations.

Historical data collected by SCADA systems can support process analysis, production reporting, maintenance planning, and investigation of deviations. The integration of SCADA with manufacturing execution systems (MES) and enterprise resource planning systems (ERP) can improve information exchange between operational and management levels. Nevertheless, SCADA monitoring alone does

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not guarantee food safety. Critical control points must be identified through an appropriate food safety management system, and monitoring procedures must meet applicable regulatory and validation requirements.

Conclusion. The study demonstrates that modern automation methods have significant potential to improve technological process management in the food industry. The integration of programmable logic controllers, SCADA systems, industrial Internet of Things technologies, artificial intelligence, machine learning, robotics, computer vision, and digital twins can contribute to higher operational efficiency, improved product quality, more reliable equipment operation, and better resource management. Traditional automation technologies remain essential for reliable process control, while intelligent digital systems provide additional capabilities for prediction, optimization, and data-driven decision-making. The research also indicates that successful automation depends on technological compatibility, data quality, cybersecurity, qualified personnel, and appropriate economic planning. A key conclusion is that food manufacturing automation must prioritize food safety and validated technological requirements rather than production efficiency alone. For food manufacturing enterprises in Uzbekistan, gradual implementation of modular automation technologies, workforce development, and cooperation between industry and research institutions represent promising modernization strategies. Future research should focus on experimental evaluation of integrated automation systems, development of process-specific intelligent control algorithms, and assessment of their technical and economic effectiveness under real production conditions.

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