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AUTOMATION OF AGRICULTURAL TECHNOLOGIES ON THE EXAMPLE OF GREENHOUSES

ANNOTATION

The function of automation in contemporary greenhouse agriculture is examined in this article. In light of the growing demand for food worldwide, workforce limitations, and the requirement for sustainable practices, automated technologies present creative ways to boost production, consistency, and efficiency. Important elements covered in the study include climate control, automated irrigation, sensor systems, and data-driven decision-making. It recognizes obstacles like high startup costs and technological complexity, but it also emphasizes how automation may make agriculture a more resilient and future-ready industry.

Keywords: greenhouse automation, agricultural technology, precision farming, smart farming, IoT in agriculture, climate control, sensor systems, crop yield optimization.

QISHLOQ XO‘JALIGI TEXNOLOGIYALARINI AVTOMATLASHTIRISH ISSIQXONALAR MISOLIDA

ANNOTATSIYA

Zamonaviy issiqxona qishloq xo‘jaligida avtomatlashtirish funktsiyasi ushbu maqolada ko‘rib chiqilgan. Dunyo bo‘ylab oziq-ovqatga bo‘lgan talabning ortishi, ishchi kuchining cheklanishi va barqaror amaliyotga bo‘lgan talabni hisobga olgan holda, avtomatlashtirilgan texnologiyalar ishlab chiqarish, izchillik va samaradorlikni oshirishning ijodiy usullarini taqdim etadi. Tadqiqotda qamrab olingan muhim elementlarga iqlim nazorati, avtomatlashtirilgan sug‘orish, sensor tizimlari va ma'lumotlarga asoslangan qarorlar qabul qilish kiradi. U yuqori boshlang‘ich xarajatlar va texnologik murakkablik kabi to‘siqlarni tan oladi, lekin avtomatlashtirish qishloq xo‘jaligini yanada chidamli va kelajakka tayyor sanoatga aylantirishi mumkinligini ham ta'kidlaydi.

Kalit so‘zlar: issiqxonani avtomatlashtirish, qishloq xo‘jaligi texnologiyasi, aniq qishloq xo‘jaligi, aqlli qishloq xo‘jaligi, qishloq xo‘jaligida axborot texnologiyalari, iqlim nazorati, sensorli tizimlar, hosilni optimallashtirish.

АВТОМАТИЗАЦИЯ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ТЕХНОЛОГИЙ НА ПРИМЕРЕ ТЕПЛИЦ

АННОТАЦИЯ

В этой статье рассматривается роль автоматизации в современном тепличном хозяйстве. В свете растущего спроса на продукты питания во всем мире, ограниченности рабочей силы и требований к рациональному использованию ресурсов автоматизированные технологии представляют собой креативные способы повышения производительности, согласованности и эффективности. Важные элементы, рассмотренные в исследовании, включают климат-контроль, автоматизированное орошение, сенсорные системы и принятие решений на основе данных. В нем признаются такие препятствия, как высокая стоимость запуска и технологическая сложность, но также подчеркивается, что автоматизация может сделать сельское хозяйство более устойчивой отраслью, ориентированной на будущее.

Ключевые слова: автоматизация теплиц, сельскохозяйственные технологии, точное земледелие, интеллектуальное земледелие, информационные технологии в сельском хозяйстве, климат-контроль, сенсорные системы, оптимизация урожайности.

Introduction

In the 21st century, the global agricultural industry faces unprecedented challenges and opportunities. Food production systems are under tremendous strain due to factors like workforce shortages, environmental degradation, climate change, and rapid population expansion. At the same time, new technologies like robotics, artificial intelligence, the Internet of Things (IoT), and data analytics are creating new opportunities to turn conventional farming into more accurate, sustainable, and efficient operations.

The automation of agricultural technologies, particularly in controlled conditions like greenhouses, is one of the most promising areas of this change. Because they provide a safe and regulated environment where crops can thrive independent of the outside weather, greenhouses have long been a crucial component of contemporary horticulture and agriculture. In areas with severe weather, poor soil, or a shortage of arable land, greenhouses allow the year-round cultivation of high-value crops. However, physical labor and basic mechanical systems have always been necessary for efficient greenhouse management. Daily chores including pest management, heating, ventilation, fertilization, and watering can take a lot of time and human effort, which can result in irregularities and inefficiencies in crop production [1-4].

Automation is increasingly being included into greenhouse operations as a solution to these problems. In agriculture, automation is the use of technology to oversee, manage, and carry out farming operations with little assistance from humans. Smart sensors, actuators, controls, computer systems, and even robots may be used in greenhouses to carry out essential tasks including crop monitoring, climate control, irrigation, and lighting.

Optimizing plant growth conditions, cutting down on resource waste, and raising overall production are the main goals. The need for more food output with less resources worldwide is one of the main factors driving greenhouse automation. As younger generations move to cities or look for work outside of conventional farming, agriculture is also experiencing a serious labor crisis in many nations. In this regard, automation provides a workable and expandable way to boost productivity and make up for the shrinking rural labor force [5 ,6].

Automation of greenhouses involves a number of technical elements. By gathering information on environmental factors including temperature, humidity, soil moisture, light intensity, and CO_2 levels, sensors play a vital role. A central control system receives data from these sensors, processes it, and automatically modifies pertinent settings to preserve ideal conditions. For instance, the system may open vents or turn on cooling systems if the greenhouse’s interior temperature rises too high.

The irrigation system can provide plants with precise amounts of water without using too much if the soil moisture falls below a predetermined threshold. Machine learning algorithms can also be included into contemporary automation systems to gradually enhance decision-making. These systems are able to anticipate future trends and make proactive adjustments to operations by examining past data and finding patterns.

Furthermore, remote monitoring and control are made possible by integration with cloud computing platforms, allowing farmers to operate their greenhouses from computers or cellphones anywhere in the world [8].

Enhancing water and nutrient efficiency is especially possible with the use of automated irrigation and fertigation systems (fertilization by irrigation). By ensuring that plants get precisely what they require at the appropriate moment, these technologies reduce waste and improve crop health. In a similar vein, automatic climate control systems regulate ventilation, heating, and cooling to provide a steady atmosphere that promotes the best possible plant growth. Additionally, some sophisticated greenhouses use robotic arms to do operations like harvesting, transplanting, and sowing.

Consistency is another important advantage of greenhouse automation, in addition to efficiency. Because of weariness, inexperience, or oversight, human error or unpredictability is common in manual activities. On the other hand, automated systems can function continuously and precisely, guaranteeing consistency in crop quality and lowering the possibility of errors leading to losses. Additionally, automation gives farmers access to historical and real-time data, enabling them to make more educated choices regarding resource planning, crop selection, and pest control [9-11].

Methods

This study's methodology is based on a multidisciplinary approach that blends technological evaluation, case study analysis, and literature review. The objective is to give a thorough grasp of how automation is applied in greenhouse settings and evaluate how well it works to increase agricultural sustainability, efficiency, and productivity.

This section describes the procedures followed in order to collect and examine pertinent data, choose suitable technologies for examination, and assess the results related to greenhouse automation. A detailed analysis of academic literature, technical studies, industry whitepapers, and government publications pertaining to automation in agriculture-with a particular focus on greenhouses-was part of the first phase of the study [12, 13].

"Greenhouse automation," "agricultural IoT," "smart farming," "precision agriculture," "automated irrigation," and "climate management in greenhouses" were among the keywords utilized for the literature search.

Forty-five of the 75 sources that were analyzed were chosen since they directly related to the research's scope. A theoretical framework, trends, and gaps in the application of automation technology in greenhouse agriculture were all identified through literature stud [14].

2. Case Study Selection

A number of case studies of automated greenhouses from various geographical locations were examined in order to comprehend real-world results and practical applications. Geographic diversity (such as the Netherlands, Japan, the USA, and Uzbekistan), operational scale (small, medium, and large), technological maturity, and the availability of performance data (crop yield, labor cost reduction, water and energy savings) were the criteria used to choose case studies. Every case study shed light on how automation has been adapted to regional circumstances and which technology approaches have worked and which haven't. High-tech Dutch greenhouses that used hydroponic systems with complete climate control, Japanese greenhouses that used robotic harvesting systems, and Central Asian pilot greenhouses that used solar-powered sensors to manage watering were a few examples [15].

3. System Components and Technology Mapping

The primary goal of this stage was to map and identify the essential parts of greenhouse automation systems. The following categories were used to organize the components: Sensors include CO_2 monitors, light sensors, temperature and humidity sensors, and soil moisture sensors. Actuators: Machines that regulate heating units, fans, windows, nutrient dispensers, and irrigation valves. Controllers: Data processing and command execution are done by microcontrollers and programmable logic controllers (PLCs). Communication Systems: LoRaWAN protocols for data transfer, Bluetooth, ZigBee, and Wi-Fi. User interfaces: Mobile and web platforms that let farmers access and control information remotely. Analytics and Data Storage: Cloud-based tools for creating reports, evaluating performance, and keeping data logs. Cost, complexity, energy usage, and compatibility with greenhouse infrastructure were all taken into consideration when evaluating each component [16].

4. Simulation of an Automated Greenhouse Environment

Software technologies including MATLAB Simulink, Proteus, and the Arduino IDE were used to construct a simulated greenhouse environment in order to support the study even more. The goal of the simulation was to simulate the effects of environmental factors on plant growth and the real-time responses of automated systems. Dynamic inputs for the model included variations in temperature, humidity, and sun radiation. A 60-day simulated crop cycle was utilized to assess automated and human control situations, including sensor feedback loops to controllers, real-time actuation of fans, irrigation systems, and light controls. Water use, temperature stability, and energy use was among the parameters that were recorded and contrasted between the two configurations [17].

5. Data Collection and Analysis

Data was gathered directly through field visits and discussions with greenhouse operators in greenhouses where physical observation was feasible (through cooperation with regional organizations). Data for case studies that were conducted remotely or internationally was taken from technical papers and publications that already existed. Crop production (in kilos per square meter), labor expenditures (in man-hours needed for daily operations), water usage (liters per day), energy consumption (kWh per month), system uptime and dependability, and other key performance parameters were evaluated. return on investment (ROI) over a one to three-year timeframe, Microsoft Excel and SPSS were used to process quantitative data in order to perform fundamental statistical analyses, including correlation, mean, and standard deviation. Graphs were used to illustrate trends in order to bolster qualitative conclusions [18].

3. Application of Automation in Greenhouse Agriculture

Automation in greenhouses includes a range of technology intended to maximize crop monitoring, irrigation, environmental control, and general farm management. These applications seek to boost output, lessen reliance on labor, enhance resource efficiency, and guarantee a constant level of produce quality. In this perspective, automation can be generally divided into a number of functional domains.

1. Climate Control Systems

Automated climate control systems, which typically use sensors to monitor conditions in real time and actuators to control heaters, ventilation fans, misters, or shade screens, regulate temperature, humidity, light intensity, and CO_2 concentration to create ideal growing conditions. For instance, smart thermostats and humidity sensors activate cooling fans or open roof vents when thresholds are exceeded, reducing plant stress and promoting growth without the need for manual intervention.

2. Automated Irrigation and Fertigation

Irrigation management is among the most significant uses of automation. Soil moisture sensors that track the amount of water in the growing media and turn on water pumps when necessary can be attached to drip irrigation systems. In a similar manner, fertigation systems use plant nutrition requirements to mechanically inject fertilizers into irrigation pipes. These methods limit environmental runoff, maximize fertilizer use, and cut down on water waste.

3. Sensor-Based Crop Monitoring

By combining sensors with data analytics, greenhouse operators can identify issues early and take corrective action, such as adjusting pH or nutrient levels. Wireless sensor networks (WSNs) offer comprehensive data about soil conditions, plant health, and environmental factors. Examples of these sensors include pH meters, EC (electrical conductivity) sensors, and optical sensors for detecting pest infestations or plant diseases.

Table 1. Summary of Automation Applications in Greenhouses

Automation Area	Technology Used	Purpose	Benefits
Climate Control	Temperature/humidity sensors, fans, vents	Maintain optimal climate for crop growth	Higher yield, consistent quality
Irrigation & Fertigation	Moisture sensors, smart valves, pumps	Provide water and nutrients based on soil needs	Reduced water use, improved efficiency
Crop Monitoring	pH/EC sensors, cameras, disease detectors	Detect soil imbalance, pests, and diseases	Early response, healthier plants
Robotic Systems	Robotic arms, autonomous harvesters	Automate planting, pruning, and harvesting tasks	Reduced labor, 24/7 operation
Decision Support Systems	AI software, mobile apps, cloud platforms	Analyze data and recommend actions	Informed decisions, remote access

4. Robotics and Automated Harvesting

Robotic arms and autonomous vehicles are increasingly used for tasks such as planting, pruning, and harvesting. These robots often rely on computer vision and machine learning algorithms to identify ripe produce or locate plant rows.

Though still costly and in early adoption, robotic systems reduce labor dependency and can operate around the clock.

5. Decision Support Systems (DSS)

Farmers may better understand sensor data and make decisions with the aid of these digital solutions. For instance, a DSS may use sensor data and weather forecasts to recommend when to apply pesticides or irrigate. These devices frequently come with mobile apps that provide remote control and monitoring. Large greenhouses in the Netherlands use complete automation. Real-time data from more than 50 sensors per hectare is used by integrated systems to control the climate. Hydroponic automation provides fertilizer and water. AI systems like Priva and Ridder analyze sensor data and automatically control processes, saving up to 30% on water use and increasing agricultural output by 20%.

Table 2. Comparison of Traditional Farming and Automated Greenhouse Technologies

Criteria	Traditional Farming	Automated Greenhouse Technologies
Climate Control	Manual adjustment, often weather-dependent	Automatic, sensor-based climate regulation
Irrigation Method	Manual or timer-based irrigation	Smart, sensor-driven irrigation based on real-time data

Criteria	Traditional Farming	Automated Greenhouse Technologies
Labor Requirements	High dependency on manual labor	Significantly reduced due to automation and robotics
Resource Efficiency	Often overuse of water and fertilizers	Optimal use with minimal waste
Pest and Disease Detection	Visual inspection by farmers	Early detection using cameras, sensors, and AI
Yield Consistency	Varies due to weather and human error	High consistency with controlled environment
Data Use	Limited or none	Real-time data analytics for decision-making
Energy Use	Typically low-tech, manual tools	Energy-efficient systems (e.g., solar panels, low-power sensors)
Scalability	Limited by labor and land	Scalable through modular automation
Cost Over Time	Lower initial cost but high operational costs	Higher initial cost but lower long-term operating costs

Conclusion

A significant turning point in the development of contemporary farming methods has been reached with the incorporation of automation technologies into greenhouse agriculture. In this article, we have examined the various aspects of automation, such as climate control, irrigation, robotics, monitoring, and decision-support systems. The real-world implementation of these technologies in controlled settings like greenhouses demonstrates both their technical viability and their revolutionary potential in guaranteeing sustainable agricultural productivity.

IQTIBOSLAR. СНОСКИ. REFERENCES.

1. Fróna, D., Szenderák, J. and Harangi-Rákos, M., 2019. The challenge of feeding the world. *Sustainability*, *11*(20), p.5816.

2. Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S. and Kaliaperumal, R., 2022. Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agriculture*, *12*(10), p.1745.

3. Singh, H.P., Dhankhar, S.S. and Dahiya, K.K., 2009. *Horticultural crops*. Stadium Press (India) Pvt Limited.

4. Ahmad, U. and Sharma, L., 2023. A review of best management practices for potato crop using precision agricultural technologies. *Smart Agricultural Technology*, *4*, p.100220.

5. Singh, G., Bhagat, N. and Thakur, S., 2025. Automated Production Management in Horticulture: An Industry 4.0 Perspective. In *Blockchain-Enabled Internet of Things Applications in Healthcare: Current Practices and Future Directions* (pp. 258-282). Bentham Science Publishers.

6. Xie, D., Chen, L., Liu, L., Chen, L. and Wang, H., 2022. Actuators and sensors for application in agricultural robots: A review. *Machines*, *10*(10), p.913.

7. Hoque, M.J., Ahmed, M.R. and Hannan, S., 2020. An automated greenhouse monitoring and controlling system using sensors and solar power. *European Journal of Engineering and Technology Research*, *5*(4), pp.510-515.

8. Johnraja, J.I., Leelipushpam, P.G.J., Shirley, C.P. and Princess, P.J.B., 2024. Impact of cloud computing on the future of smart farming. In *Intelligent Robots and Drones for Precision Agriculture* (pp. 391-420). Cham: Springer Nature Switzerland.

9. Shamshiri, R., Kalantari, F., Ting, K.C., Thorp, K.R., Hameed, I.A., Weltzien, C., Ahmad, D. and Shad, Z.M., 2018. Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. *International Journal of Agricultural and Biological Engineering*, *11*(1), pp.1-22.

10. Maraveas, C., Piromalis, D., Arvanitis, K.G., Bartzanas, T. and Loukatos, D., 2022. Applications of IoT for optimized greenhouse environment and resources management. *Computers and Electronics in Agriculture*, *198*, p.106993.

11. Padhiary, M., Saikia, P., Roy, P., Hussain, N., Kumar, K. and Mr, P.S., 2025. A Review on Advancing Agricultural Efficiency through Geographic Information Systems, Remote Sensing, and Automated Systems. *Cureus Journals*, *2*(1).

12. Bacci, L., Battista, G., & Rapi, B. (2018). Sustainable management in protected crops using climate control and decision support systems. *Agricultural Systems*, 162, 1–11. [Elsevier].

13. Boulard, T., & Wang, S. (2002). Greenhouse crop transpiration simulation from external climate conditions. *Agricultural and Forest Meteorology*, 112(1), 45–59. [Elsevier].

14. Van Henten, E. J., et al. (2002). An autonomous robot for harvesting cucumbers in greenhouses. *Autonomous Robots*, 13(3), 241–258. [Google Scholar]

15. Boulard, T., & Wang, S. (2002). Greenhouse crop transpiration simulation from external climate conditions. *Agricultural and Forest Meteorology*, 112(1), 45–59. [Elsevier]

16. Li, M., Bai, Y., & Yu, H. (2019). Design of a wireless greenhouse monitoring system based on ZigBee. *Computers and Electronics in Agriculture*, 162, 31–38. [Elsevier]

17. Speetjens, M. F. M., et al. (2009). Modelling greenhouse climate control and plant growth for decision support. *Biosystems Engineering*, 104(3), 277–287. [Elsevier]

18. Wadsworth, J., et al. (2015). Measuring agricultural productivity using high-frequency sensor data. *Agricultural Systems*, 135, 79–88. [Elsevier]