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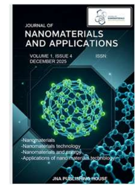

PLC Application in Smart Livestock: Design and Operation of Automatic Control Systems

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Abstract: In the context of digital transformation in agriculture, this study proposes a novel PLC-based smart livestock management system that integrates multi-gas environmental sensing, automatic control, and cloud-based remote monitoring into a unified architecture. Unlike existing approaches that focus mainly on single-parameter monitoring or manual intervention, the proposed system incorporates a wireless sensor network capable of simultaneously measuring temperature, humidity, light intensity, wind speed, and critical gases (oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), and ammonia (NH_3)) to comprehensively assess barn microclimate conditions. Based on real-time sensor data, a Programmable Logic Controller (PLC) executes automatic and semi-automatic control strategies to regulate ventilation, cooling, lighting, and roof mechanisms, ensuring stable and safe environmental conditions for livestock. Furthermore, a cloud-connected platform enables remote supervision, data storage, scenario-based operation, and real-time alerts via web and mobile applications, enhancing operational flexibility and management efficiency. The system was deployed and evaluated in a commercial poultry farm in Hung Yen, Vietnam, where experimental results demonstrated improved microclimate stability, reduced labor costs, and increased poultry survival rates compared to traditional farming practices. These findings confirm the novelty, feasibility, and scalability of integrating PLC-based automation with multi-gas sensing and cloud technologies, offering a cost-effective and practical solution for modern smart livestock farming..

Keywords: Agricultural IoT; Environmental sensors; High-tech livestock; Livestock automation; Programmable Logic Controller; Smart control

1. Introduction

In the context of agriculture strongly transforming towards high technology and automation, the application of smart solutions to the livestock industry has become an inevitable trend globally. Automation not only helps save costs, minimize disease risks but also contributes to improving product quality and productivity, meeting the increasing demand of the market. Recent studies have shown outstanding efficiency when integrating advanced technologies such as artificial of Artificial Intelligence (AI), smart algorithms, sensors and Big Data analysis into livestock [1, 2]. Many international publications since 2015 have demonstrated the great potential of technology in this field [3]. For example, chicken vocalization analysis has been used to detect early signs of infection, making disease control more effective. Video-based livestock behavior monitoring systems have also been developed to detect diseases in a timely manner. At the same time, intelligent algorithms have been applied to optimize feeding processes, health management, and productivity prediction [4]. However, one of the major challenges facing livestock farming remains the shortage of skilled human resources and the need for continuous, high-precision management of the barn environment. Manual data collection on temperature, humidity, light, or air quality is not only time-consuming but also unreliable, making the control of equipment such as fans, water valves, or roofs inefficient. To overcome this problem, Programmable Logic Controller (PLC)-based automation systems have been proposed as a key solution [5]. With its stability, flexibility and easy programming, Programmable Logic Controllers (PLCs) have been widely used in many fields, from industry to agriculture [6–8].

Many studies have applied PLCs to automate production processes, such as in animal feed production systems. Although many automated systems have been deployed, most of the previous studies have focused on monitoring and controlling production lines. These systems have not yet integrated environmental sensors to comprehensively process and automatically control microclimate factors inside livestock barns. In this context, our study shows a comprehensive and novel solution. Specifically, we have developed an automated livestock farm management system based on PLC, integrating wireless communication networks and cloud computing [8, 9].

The new and different point of this study compared to previous publications is: The system not only monitors basic parameters but also collects and analyzes data from sensors measuring temperature, humidity, light, wind speed, O_2, CO, CO_2 and NH_3. Based on data from the sensors, the system is capable of issuing automatic or semi-automatic control commands to devices such as fans, sprinklers, lights, and roof cooling systems. This is different from systems that simply control the production line. The system allows farm owners to conveniently monitor and manage all activities via the internet, from anywhere, via computer or mobile application. Data is stored in a cloud database for analysis and optimization decision making. Our study not only introduces a theoretical model but is also tested in practice at a chicken farm in Kim Dong, Hung Yen, Vietnam. We have evaluated the effectiveness of the system, thereby proposing a comprehensive solution to digitize and automate the entire livestock farming process, towards a smart livestock farming model.

In this study, the Programmable Logic Controller (PLC) plays a central role as the local intelligent control unit, responsible not only for executing predefined control logic but also for ensuring real-time responsiveness, system reliability, and operational safety in livestock farming environments. Unlike cloud-only or sensor-based monitoring solutions, the PLC enables autonomous decision-making at the farm level, even under unstable network conditions

The selection of a Programmable Logic Controller (PLC) as the core control device is motivated by the specific operational requirements of high-tech livestock farming. Livestock environments are characterized by high humidity, dust, electrical noise, and the need for continuous operation. Compared to microcontroller-based or purely cloud-dependent solutions, PLCs offer superior industrial-grade reliability, deterministic real-time control, and long-term operational stability, making them particularly suitable for mission-critical agricultural applications.

2. Design

The PLC functions as the core controller of the system, collecting real-time data from distributed environmental sensors, processing control algorithms locally, and directly actuating farm equipment such as ventilation fans, cooling systems, lighting, and roof mechanisms. By performing edge-level decision-making, the PLC ensures deterministic control and continuous operation, even in the event of temporary internet or cloud service disruptions.

In this system, the PLC was chosen over conventional embedded controllers due to its ability to handle multiple industrial sensors and actuators with high immunity to environmental interference. The PLC supports modular input/output expansion, robust communication with Human–Machine Interface (HMI) devices, and seamless integration with cloud platforms, while maintaining autonomous local control in the event of network disruptions.

2.1. System model

In the context of agriculture strongly transforming towards high technology and automation, the application of smart solutions to the livestock industry has become an inevitable trend globally. Automation not only helps save costs, minimize disease risks but also contributes to improving product quality and productivity, meeting the increasing demand of the market. The livestock farm management system model is designed according to a layered architecture, integrating Internet of Things (IoT) technology and cloud computing to optimize monitoring and control [10], [11]. Recent studies highlight both the current applications and challenges of IoT in agriculture [12] as well as the critical aspects of security and privacy in industrial IoT (IIoT) environments, which must be considered when deploying such smart livestock systems [13]. The system includes three main layers: the sensor and actuator layer, the local control layer (Edge computing), and the cloud layer (Cloud) [14].

On the other hand: Previous international studies have shown that IoT and PLC-based automated livestock systems can improve operational efficiency by 10–25% by optimizing microclimate control and reducing manual intervention [9], [14]. Some large-scale farm application models have also shown significant reductions in operating costs, mainly due to reduced labor and energy savings, with savings of 30–50% depending on farm conditions [18]. In addition, cloud-based IoT systems have demonstrated the ability to flexibly scale up to tens of thousands of livestock without compromising data stability and response speed [10], [12]. Research on precision livestock farming also confirms that automated models when deployed on a large scale maintain higher control accuracy than semi-automated models, especially in temperature and toxic gas management [4]. These results create a clear scientific foundation for the application of PLC combined with IoT in livestock farming in Vietnam.

2.2.The system layers

Sensor and actuator layer: This is the physical layer, directly collecting data and executing control commands. Smart sensors are placed throughout the barn to collect microclimate parameters such as temperature, humidity, light, wind speed, along with concentrations of toxic gases such as O_2, CO, CO_2 and NH_3 [15]. The actuators include ventilation fans, sprinklers, lighting, and roof cooling systems, which are automatically activated based on sensor data analysis.

Local control layer Programmable Logic Controller (PLC): PLC acts as the brain of the on-site system [16]. Signals from sensors are fed into the PLC for real-time processing. The PLC performs automatic control tasks based on pre-programmed algorithms and set threshold values. The flexibility of the PLC allows it to operate independently even when the internet connection is lost, ensuring the stability and safety of the barn. The PLC also has the task of communicating with the Human Machine Interface (HMI) screen to display the status and allow the user to manually control on-site.

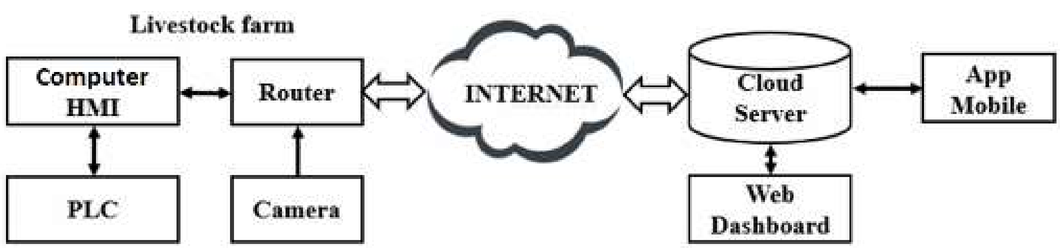

Figure 1. PLC data transmission system model

Cloud layer: This layer receives data from the PLC through network devices (Router) and transmits it to the cloud server [17]. The data is then stored and analyzed to provide overview information, data history, and in-depth reports [18]. The user interface on the web dashboard and mobile application is connected to the cloud server, allowing the farm manager to conveniently monitor and control the system remotely. In the Figure 1, the cloud layer also integrates advanced functions such as real-time alerts via Short Message Service (SMS) or email, and big data management to support trend analysis and forecasting.

The programmable logic controller (PLC) serves as a microprocessor that executes commands stored in its program memory. It receives input data, processes the program logic, generates the corresponding output, and transmits control signals directly to actuators to perform the desired actions. This workflow ensures seamless processing from input to output within the automated system. PLC has a functional block diagram as shown in Figure 2.

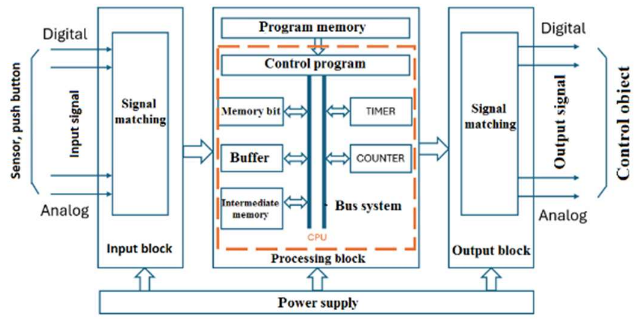

Figure 2. Functional block diagram of PLC

2.3. System design block diagram at the farm

This diagram describes a closed automatic control system, in which the PLC plays a central role in collecting data, processing and controlling devices based on measurement parameters from sensors and pre-programmed programs (Figure 3). This system can be monitored and controlled remotely via the Internet, helping to increase the efficiency and reliability of the production or operation process. Environmental parameter signals at the barn are collected by smart sensors and transmitted to the PLC. The PLC processes the information displayed on the HMI screen and transmits it to the router to transmit to the server via the internet. Information from the server network on the internet is transmitted to the PLC to control electrical devices such as fans, water pumps, humidifiers, etc. through contactors.

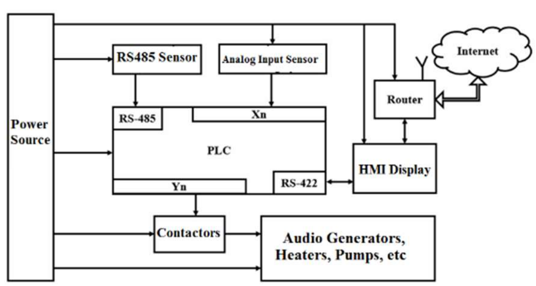

Figure 3. Monitoring and control system at the farm

2.4. Diagram of automatic monitoring and control system for chicken farms

Figure 4 is a diagram of the automatic monitoring and control system including hardware and software. The hardware is the system that collects data and controls devices including: Global System for Mobile Communications (GSM) positioning sensor, O_2, CO, CO_2, NH_3 gas sensor.

The system controls the surveillance camera, ventilation fan, warning siren system, heating device, humidifier, water pump to cool the roof of the barn, motor to pull the canopy, lower the canopy when needed.

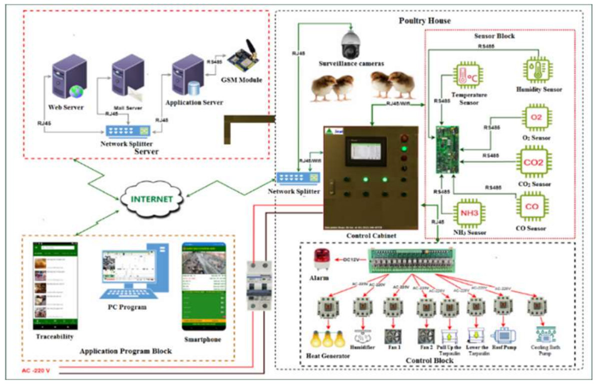

Figure 4. Diagram of the automatic monitoring and control system of the chicken farm

The control software operates in two modes, manual mode and automatic mode (Figure 5).

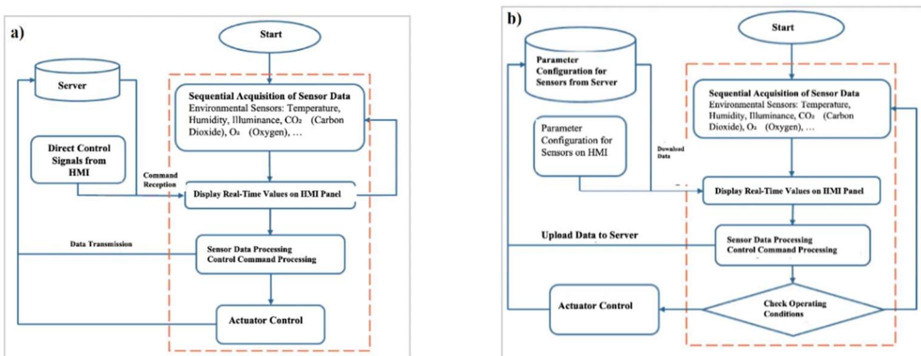

Figure 5. Algorithm diagram for the controller

With manual control mode, you can operate directly on the HMI screen or on the Web Dashboard and Mobile App. As for automatic mode, depending on the scenario of each different livestock farm, the appropriate sensor parameters will be set. According to the above algorithm diagram, if the current sensor value is equal to or reaches the allowable threshold compared to the set parameter value, this case is correct and the program ends. Conversely, if the current measured sensor values do not satisfy the conditions with the set parameters, the program executes the control commands of the actuator to change the environmental conditions back to the state according to the set scenario.

The server-side software uses the communication between the controller and the sensors protocol to communicate with other functional blocks in the system, which is responsible for managing devices and processing data from sensors, providing a user interface for farm managers, performing automatic functions based on sensor data analysis, and promptly issuing real-time alerts (Figure 6).

The software module on the computer is designed and built to monitor, control, set up system operating scenarios, manage users and create reports. The main interface of the program displays all the operating information of a barn: including barn information, current environmental parameter information of the barn, real-time sensor value graph, status information of peripheral devices, warning information, live camera images installed in the barn. The system block includes functions for user management; management of peripheral devices: Camera; video recorder; monitoring and control equipment for environmental parameters of poultry barns; Email, SMS information; Data backup and recovery functions. The poultry farm block includes functions for managing information about farms, barns, and poultry breeds. Monitoring and controlling the barn in terms of temperature, humidity, fans, cooling water spray, roof control, warning siren.

Care and disease prevention block: Includes the function of managing care information, food, vaccines, disease information, managing seasonal disease information.

Operation scenario block: Care scenario, vaccine usage scenario, temperature scenario, humidity scenario, barn air quality scenario, barn operation scenario.

Reporting block: Building reports on equipment (cameras, recorders, control devices, etc.); Reports on monitoring results; Reports on the list of poultry farms and barns; Reports on the care process, drug use; vaccines; Reports on epidemics, etc.

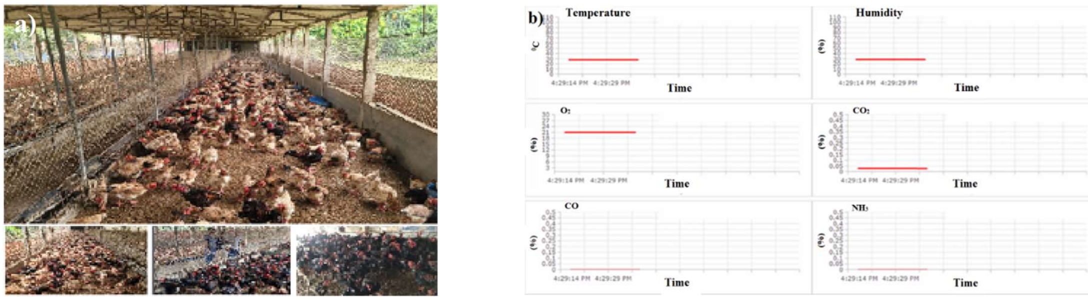

Figure 6. Main screen of the software on the computer

Support block: Includes functions on system introduction; user manual; software copyright; online support. The software on the phone has an interface as shown in Figure 7.

The user enters the account information to enter the system. The user can monitor and control the list of barns of the registered farm. At the barn monitoring and control interface, the user can control ON/OFF of peripheral devices (humidification, heating, turning on/off the fan, pulling/lowering the roof, etc). Or switch to automatic monitoring mode, controlling according to the scenario.

Figure 7. Main screen of the software on the phone

Experimental deployment and sensor calibration: The proposed PLC-based control system was deployed in a commercial poultry farm located in Kim Dong district, Hung Yen province, Vietnam. The experimental setup consisted of one closed-type poultry house with a capacity of approximately 10,000 broiler chickens. Prior to deployment, all environmental sensors (temperature, humidity, O_2, CO, CO_2, and NH_3) were calibrated using manufacturer-recommended procedures and cross-checked with reference measuring devices to ensure acceptable accuracy. The calibration process was conducted before the start of the experiment and periodically verified during operation to minimize measurement drift.

3. Results and Discussion

This high-tech livestock management system is designed to not only automate processes but also ensure the highest level of continuity, safety and efficiency of operations. The integration of advanced features helps to optimize every aspect of the farm, from environmental monitoring to data management and risk prevention.

3.1. Continuous Operation and Data Security

The first highlight of the system is the ability to operate in real time, ensuring that all reactions to the barn environment are instantaneous, without delay. The ability to automatically reconnect is an important layer of protection. When a temporary loss of connection occurs with the communication between the controller and the sensors server or software, the system will automatically restore, ensuring the continuity of the control process. This helps prevent potential problems such as water shortages or sudden temperature changes, which can cause stress or disease in livestock. In terms of security, the system is equipped with high-level security layers such as Secure Sockets Layer/Transport Layer Security (SSL/TLS). This is a key factor to protect information transmitted between devices and servers, preventing the risk of leakage or theft of important farm data, such as production data or livestock information. This level of security creates absolute trust for users, especially in the context of data becoming a valuable asset of businesses

3.2. In-depth Data Analysis and Decision Support

The system not only collects but also turns data into useful information. With the integration of a Database or backend system, all environmental parameters are systematically stored and analyzed. The management software supports the creation of in-depth reports and graphs, giving managers an overview of the development of the farm over time. These data analyses allow managers to identify trends, evaluate the effectiveness of care processes, and make data-driven decisions instead of traditional experience. For example, analyzing historical temperature and humidity can help optimize the on/off time of fans or cooling pumps, saving energy while still ensuring ideal living conditions for livestock.

3.3. Multi-layered Warning and Control System

The system is equipped with multiple layers of warning and automation to ensure absolute safety. The software will immediately alert managers when there is an emergency such as temperature exceeding the threshold, power failure, or lack of water. At the same time, the system will automatically perform corrective actions, such as activating pumps or fans to maintain a stable living environment. Specialized modules help the system operate precisely according to pre-set scenarios, including: Temperature and humidity control: The system automatically maintains temperature from 15°C to 35°C and humidity from 60% to 70% based on the age of the poultry. Improve air quality: Automatically control ventilation fans to remove toxic gases when CO, CO_2, NH_3 concentrations exceed the allowable level, while maintaining O_2 concentrations at the ideal level. In addition, the surveillance camera system not only supports monitoring development and security but also has the ability to take photos, create a database to trace the origin of food, meeting increasingly high market standards. With the ability to support care for farms with about 10,000 poultry, this system is truly a comprehensive solution, bringing livestock farming to a new level of efficiency and sustainability. Some of the efficiencies of the Programmable Logic Controller (PLC) based automatic system are shown in Table 1.

Table 1. Efficiency table when using automation

Indicators	Traditional Model	PLC	Improvement (%)
Chicken survival rate	87.4%	98.3%	+12.5%
Labor cost/month	12.000.000 VNĐ	6.200.000 VNĐ	48,3%
Leftover feed	8.1%	5.2%	2,9%
Variable temperature	±4°C	±1.5°C	Ổn định hơn
Variable humidity	±10% RH	±3% RH	Ổn định hơn

Through Table 1, we can see that the PLC model is much more effective than the traditional model. The survival rate of chickens is 12.5% higher. The automatic control system helps improve the environment to help chickens grow better, specifically reducing the amount of excess food by 2.9%. The stable operation of the system throughout the experimental period, including uninterrupted control during temporary internet outages, demonstrates the suitability of the PLC-based architecture for livestock farming. The low variability in temperature and humidity control observed in Table 1 can be directly attributed to the deterministic and real-time control capabilities of the PLC, which are difficult to achieve with non-industrial or cloud-only control platforms. The overall environmental conditions such as temperature and humidity in the barn are more stable, specifically the temperature when controlled manually fluctuates within ±4°C, when using PLC is ±1.5°C, humidity when used manually fluctuates within ±10% Relative Humidity (RH) and when using PLC is ±3% RH. Some images of the deployed system are shown in Figure 8.

Figure 8. Image of ventilation fan system, lighting, surveillance camera, environmental sensors

3.4. Comparison with International Studies: System Performance, Cost-effectiveness and Scalability

Compared with previous international studies on PLC and IoT based livestock management systems, the proposed system demonstrates competitive and, in some aspects, superior performance in terms of environmental control accuracy, operational efficiency, and economic benefits. Previous studies have reported improvements of 10–25% in operational efficiency and reductions in labor and energy costs ranging from 30–50%, depending on farm size and system complexity [9,10,14,18]. The results obtained in this study are consistent with these findings, as evidenced by the 12.5% increase in poultry survival rate, nearly 50% reduction in labor costs, and improved microclimate stability compared to traditional manual control models. In terms of system performance, the achieved temperature fluctuation range (±1.5°C) and humidity variation (±3% RH) are comparable or better than those reported in precision livestock farming systems deployed in large-scale farms in Europe and Asia [4,14]. This indicates that PLC-based control, when combined with real-time sensor networks, can provide high reliability and robustness even under variable environmental conditions. Regarding cost-effectiveness, the use of PLC technology offers a significant advantage over fully cloud-dependent or AI-centric systems reported in recent literature. While advanced AI-based solutions may achieve high analytical accuracy, they often require substantial computational resources and investment costs [3,11]. In contrast, the proposed PLC–IoT architecture balances performance and cost, making it particularly suitable for small- and medium-scale farms in developing countries, while still remaining adaptable to larger industrial farms. Scalability is another important aspect where the proposed system aligns well with international trends. Cloud-based data management and modular PLC design allow the system to be extended from a single barn to multiple barns or farms without major structural changes. Previous studies have demonstrated that IoT-enabled livestock platforms can scale to tens of thousands of animals while maintaining data stability and response speed [10,12]. The architecture presented in this study follows similar principles, suggesting strong potential for deployment across different livestock types (poultry, pigs, dairy cattle) and farm sizes with minimal customization. Overall, this comparative analysis confirms that the proposed system is not only technically feasible but also economically and operationally competitive with existing international solutions. The results support its potential as a scalable and cost-effective model for smart livestock farming, particularly in regions where investment constraints and labor shortages remain critical challenges.

3.5. Comparison of PLC-Based Control with Alternative Technologies

The selection of a control platform significantly affects system reliability, responsiveness, scalability, and overall cost in smart livestock farming. Table 2 compares the proposed PLC-based system with other commonly used control solutions, including microcontroller-based platforms, PC-based control systems, and cloud-centric IoT architectures. PLC-based controllers provide deterministic real-time performance, high immunity to electrical noise, and long-term operational stability, which are essential in harsh livestock environments characterized by dust, humidity, and continuous operation. These advantages are reflected in the stable environmental control achieved in this study, particularly the reduced temperature and humidity fluctuations reported in Table 1. In contrast, microcontroller-based systems offer lower initial costs and greater flexibility for prototyping but often lack industrial robustness and require additional hardware and software layers to achieve comparable reliability. PC-based systems enable advanced data processing but involve higher energy consumption, maintenance complexity, and vulnerability to system crashes. Cloud-only IoT solutions excel in large-scale data analytics and remote access but depend heavily on network stability, which can compromise real-time control in rural farming environments. The experimental results demonstrate that the PLC-based architecture offers an effective balance between performance, reliability, and cost. The observed improvements in poultry survival rate, labor cost reduction, and microclimate stability confirm that the advantages of PLC-based control outweigh its limitations for medium- to large-scale smart livestock farming applications.

Table 2. Comparison of control technologies for smart livestock farming

Criteria	PLC-based system	Microcontroller-based system	PC-based system	Cloud-centric IoT system
Real-time determinism	High	Medium	Medium	Low
Environmental robustness	High (industrial-grade)	Low–Medium	Medium	Medium
Dependence on internet	Low	Medium	Medium	High
Scalability	High	Medium	Medium–High	High
Initial cost	Medium	Low	High	Medium
Maintenance complexity	Low	Medium–High	High	Medium
Suitability for livestock farms	High	Medium	Medium	Medium

3.6. Validation and Accuracy of the Experimental Results

The obtained results were validated through a combination of sensor calibration, long-term operational monitoring, and comparison with historical farm data and previously reported studies. Prior to deployment, all environmental sensors were calibrated against reference instruments to ensure measurement accuracy within the manufacturer-specified tolerance range. During system operation, sensor readings were continuously logged and cross-checked to identify abnormal deviations or drift. The performance indicators reported in Table 1 were evaluated by comparing the experimental production cycle with historical records from the same farm operating under conventional manual control. This approach minimizes the influence of external factors such as farm layout, climate, and management practices, thereby enhancing the reliability of the comparison. In terms of accuracy, the achieved temperature stability (±1.5°C) and humidity variation (±3% RH) are consistent with or slightly better than values reported in international studies on PLC- and IoT-based livestock control systems, where typical fluctuations range from ±2–3°C for temperature and ±5% RH for humidity. Similarly, the observed improvement in poultry survival rate aligns with previously published results indicating survival rate increases of approximately 8–15% following the implementation of automated environmental control systems. The consistency between the obtained results, historical farm data, and findings reported in the literature confirms the validity and practical accuracy of the proposed PLC-based system. While the study focuses on applied performance evaluation rather than advanced statistical modeling, the observed improvements exceed normal operational variability, supporting the robustness and reliability of the reported outcomes.

4. Conclusion

The study has confirmed the great potential of applying Programmable Logic Controller (PLC) system in converting traditional livestock models to high technology. By integrating IoT solutions and remote monitoring interface, the system not only ensures strict control of environmental factors but also brings outstanding benefits in economic efficiency and operation. The system allows effective real-time monitoring and control, easy to operate on computers or smartphones. The user-friendly, intuitive interface helps even people without deep expertise to operate, contributing to the democratization of technology in the livestock industry. Moreover, optimizing the system has brought about clear benefits in saving resources such as water, energy, feed and especially labor, thereby significantly improving productivity and reducing production costs. The success of this model opens up a promising direction for the application of automation in agriculture, laying the foundation for further research to integrate artificial intelligence (AI) and new technologies, towards a completely smart and sustainable livestock industry.

The choice of a PLC as the core control device is a key factor contributing to the system's reliability, scalability, and practical applicability. Its industrial-grade robustness and real-time control capabilities make the PLC particularly well suited for high-tech livestock environments, where continuous operation and system resilience are critical.

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