

Integrating Real-Time IoT Based Monitoring and Dashboard Design for Closed-House Hen Farming

Andreas Handojo^{1*}, Edyg Setijarso², Siana Halim³, Tanti Octavia³

¹⁾ Faculty of Industrial Technology, Informatics Department, Petra Christian University

²⁾ Faculty of Industrial Technology, Engineer Profession Education Department, Petra Christian University

³⁾ Faculty of Industrial Technology, Industrial Engineering Department, Petra Christian University

Jl. Siwalankerto 121-131, Surabaya 60236, Indonesia

Email: handojo@petra.ac.id*, dqtaro77@gmail.com, halim@petra.ac.id, tanti@petra.ac.id

*Corresponding author

Abstract: This paper presents a comprehensive solution that integrates IoT-based hardware systems with a real-time dashboard specifically designed for closed-house poultry farming, focusing on laying hens. Since laying hens are homeothermic animals, they are sensitive to temperature and humidity. Therefore, it is essential to monitor and control these environmental factors, along with ventilation, in real time. We describe a smart monitoring system that combines sensors, microcontrollers, and Android-based dashboards to provide actionable insights into poultry health and egg production performance. This system tracks various parameters, including temperature, humidity, equipment status, and key production indicators such as Hen Day Production (HDP), Hen House Production (HHP), and Feed Conversion Ratio (FCR). Evaluations conducted with local poultry farmers have shown improved awareness, usability, and the potential for increased operational efficiency. Despite some limitations, the dashboard provides a clear overview and helps inform decisions aimed at enhancing conditions and boosting egg production. This tool enables breeders to monitor and improve the performance of their laying hens and manage feeding strategies effectively. Additionally, it can assist in controlling and enhancing the closed-house environments and ventilation systems. The system's performance and usability were evaluated through User Acceptance Testing (UAT) and production Key Performance Indicators (KPIs), confirming its potential to enhance operational efficiency.

Keywords: Closed house farm, layer hens, IoT, hen day production, feed conversion ratio, dashboard.

Introduction

Poultry farming plays a crucial role in meeting the global demand for animal protein, with laying hens being particularly valuable. Poultry meat and eggs offer several benefits compared to alternative animal-derived dietary sources [1]. Their optimal performance relies on carefully controlled environments. The Indonesian People's Poultry Association (Pinsar) has reported that the consumption of poultry eggs and meat in Indonesia is still lower than the global average. In comparison, neighboring countries such as Malaysia and Thailand have higher per capita consumption rates, as detailed in [2]. The Central Statistics Agency (BPS) noted that in 2022, the average consumption rate of local chicken or free-range eggs in Indonesia was 2,336 kilograms per capita per week. This reflects a 2.45% increase in egg consumption compared to the previous year, when the rate was only 2.28 kilograms per capita per week in 2021 [3]. The livestock industry is beginning to expand in response to the increasing demand for nutritional necessities, particularly eggs, in the aftermath of the pandemic.

This research focuses on eggs production, particularly by laying hens. Laying hens are homeothermic animals, which indicates their ability to regulate and maintain a consistent body temperature within a specific range. The average body temperature of healthy hens typically ranges from 40 to 42°C [4]. They are sensitive to weather fluctuations. Environmental factors, such as temperature and humidity, significantly impact the productivity of laying hens. In this present work, the layer hens are bred on a closed-house farm. The closed-house farm is equipped with humidity sensors, temperature sensors, exhaust fans, a cooling pad as a cooling system, curtains, and a farm controller. The controller has a security alarm that activates if there is a mismatch in the equipment's operating system. The fan control system consists of two main components: direct fans and fan control systems. The direct fans operate continuously for 24 hours, while the fan control systems depend on panel configurations, temperature settings, or humidity levels. If the direct fans unexpectedly stop working due

to motor failure or an electrical command malfunction, a warning will activate on the panel. The close-house farm features a drop curtain and a limit switch as safety measures. The curtain will automatically open if one or more direct fans are turned off. Additionally, a warning will sound if the limit switch sensor detects the curtain or when the curtain is closed.

However, the current system presents several limitations, including the lack of recorded temperature and humidity readings from sensors, which limits data access to a port connection between the computer and the mainboard on the control panel. This setup prevents real-time monitoring. Additionally, there are no daily data records or performance dashboards for farmers to track the productivity of hens in the closed-house farm. Important data to be recorded includes egg production, chicken mortality, feed consumption, water consumption, and egg productivity. Moreover, there are no security measures in place to ensure that equipment and instruments function correctly.

To achieve success in closed-loop layer farming, a complex production decision-making system is required, such as continuous process optimization, efficient resource management (feed, energy, labor), and waste minimization (e.g., feed waste, dead chickens, chicken manure). This farming system requires and generates large amounts of data. In traditional layer farming, this data is typically collected through manual recording, but many management decisions in this business depend on current conditions and must be acted upon quickly and accurately. For example, if the temperature exceeds the tolerance limit, this can cause stress in the chickens, resulting in decreased egg production and even mortality.

Therefore, this research will approach data collection in this production process by leveraging the capabilities of the Internet of Things. IoT devices here function not only as passive monitoring tools but also as a fundamental data acquisition layer that provides data for strategic managerial decisions, a challenge in the layer farming business. For example, by improving process efficiency with real-time data on critical parameters and achieving key performance indicators (KPIs) for laying hen farms (e.g., Feed Conversion Ratio/FCR, Hen Day Production/HDP), the system enables dynamic process control to optimize feed-to-egg conversion ratios and improve overall production output efficiency.

Recent advancements have demonstrated the potential of IoT technologies in transforming poultry farming practices. For instance, Goyal *et al.* [5] provided a comprehensive review of intelligent systems designed for poultry health and welfare management, emphasizing the role of IoT, artificial intelligence, and edge computing in early disease detection and environmental monitoring. Similarly, Ahmed *et al.* [6] proposed a smart poultry monitoring system that leverages IoT sensors to detect and monitor chicken behavior, utilizing machine learning algorithms to predict health status with high accuracy. Furthermore, Ojo *et al.* [7] highlights the challenges and opportunities in implementing IoT and machine learning for disease outbreak prevention and welfare assessment. These studies collectively demonstrate the significant impact of IoT-based systems in enhancing the operational efficiency and sustainability of poultry farming.

Hence closed-house farms provide a regulated environment, but they often lack real-time monitoring, remote access, and integrated dashboards. This paper addresses these shortcomings by introducing an IoT-based monitoring solution combined with a comprehensive visual dashboard. The system monitors key factors such as temperature, humidity, lighting, feed and water consumption, and production metrics through sensors and dashboards designed specifically for layer hens. We assess both the design of the system and its usability through field trials.

Methods

This section outlines a detailed explanation of the methodologies and terminology employed in this research. The terminology for layer hens and the environmental requirement for raising these hens is the first topic of discussion, followed by the egg production performance index. In addition, we describe the closed-loop farm and provide instructions on measuring the equipment that regulates the farm. Lastly, we will explain the design dashboard used for managing the farm.

Layer Hen

Laying hens refer to fully grown female chickens that are specially raised to produce eggs. The annual egg output ranges from 250 to 280 units. The egg layers analyzed in this research are of the Hy-line brown strain.

The Hy-line brown strain is capable of 98% growth, 97% egg laying, and 95–96% peak output. At the 17-week growth phase, the body weight ranges between 1.40 and 1.48kg. This laying hen begins producing eggs at 18 weeks of age, and egg production continues until old age, around two years [8].

Environmental factors, such as temperature and humidity, significantly impact the productivity of laying hens. The optimal temperature range for laying breeds of hens, often known as the thermoneutral zone, is between 18 and 27 degrees Celsius. Laying hens create less body heat in this temperature range, allowing for more efficient energy usage. Laying hens subjected to external temperatures beyond the thermoneutral range will encounter heat stress, prompting their physiological defensive mechanisms, such as panting [9]. Kim *et al.* [10] found that the negative impacts of heat stress on laying hens are comparable when they are subjected to temperatures of 32°C and 27°C. Research has demonstrated that heat stress in laying hens can lead to decreased feed intake, reduced heat generation, and changes in blood flow from internal organs to the body surface to disperse heat [11].

The optimal relative humidity range for chicken development typically falls between 50% and 70% [12]. The temperature and humidity should be adjusted to get the ideal balance. Figure 1 illustrates the correlation between relative humidity and temperature in producing laying hens (Green – comfort state; Yellow – alert state; orange – danger state; red – emergency state).

		Relative Humidity (%)																			
		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Temperature	20	63	63	63	64	64	64	64	65	65	65	66	66	66	66	67	67	67	67	68	68
	22	64	65	65	66	66	66	67	67	67	68	68	69	69	69	70	70	70	71	71	71
	24	66	67	67	68	68	69	69	70	70	70	71	71	72	72	73	73	74	74	75	75
	26	68	69	69	70	70	71	71	73	73	73	74	74	75	75	76	77	77	78	78	79
	28	70	70	71	72	72	73	74	75	75	76	76	77	78	78	79	80	80	81	82	82
	30	71	72	73	74	74	75	76	78	78	78	79	80	81	81	82	83	84	84	85	86
	32	73	74	75	76	77	77	78	80	80	81	82	83	84	84	85	86	87	88	89	90
	34	75	76	77	78	79	80	81	83	83	84	84	85	86	87	88	89	90	91	92	93
	36	77	78	79	80	81	82	83	85	85	86	87	88	89	90	91	93	94	95	96	97
	38	78	79	81	82	83	84	85	88	88	89	90	91	92	93	95	96	97	98	99	100

Figure 1. Heat stress index [13]

Closed House Farm Requirements

Proper shelter is a critical aspect of managing poultry. Coops play a vital role in the success of farmers using intensive techniques for raising their livestock. They protect the hens from harsh midday heat, rain, wind, cold temperatures, and predators. Additionally, coops help farmers monitor their poultry operations, ensuring that chickens are adequately fed, hydrated, and cared for regarding their health.

A closed-house farm is a facility that is designed to manage heat, water vapor, and hazardous gases like ammonia effectively within the closed-house while also ensuring enough oxygen supply for chickens [14]. To extract ammonia and particles, an exhaust fan is required. We also need to specify the number and duration of the exhaust fan in the closed house. The closed house also needs ventilation, an inlet, and an outlet. The inlet receives purified air from the exterior and the outlet, eliminating carbon dioxide and ammonia gas and reducing air humidity and heat accumulation within the closed house.

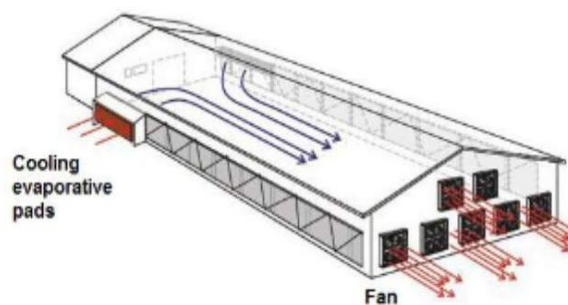


Figure 2. A close-house farm illustration [16]

Light has a crucial role in the visual process since it triggers internal biological rhythms and stimulates the secretion of hormones. Laying hens requires a maximum of 16 hours of light exposure with an intensity ranging from 10 to 20 lux [15]. The close house also needs a cooling pad. A cooling pad is a device that uses water evaporation to provide air conditioning. As hot air from outside the cage passes over the cooling pad, the water absorbs heat energy from the air, causing the water to evaporate. This process reduces the temperature of the air entering the cage [16], [17]. In the implemented system, the closed house farm has dimensions of 100 x 13 m, with a total of 16 exhaust fans, 3 cooling pads, 4 lights, 1 curtain. Figure 2 illustrates a closed-house farm. Failure management mechanisms such as emergency curtain drops and alarms are installed to handle system faults

Hardware Architecture

The hardware architecture of the system consists of several key components, each playing a critical role in effective farm management:

Microcontroller (Arduino Mega 2560): This serves as the central processing unit, responsible for collecting sensor data, executing control logic, and managing device actuation. Its enhanced memory (8KB SRAM and 256KB Flash) supports complex processing tasks and integration of multiple sensors. To ensure the hardware is economically feasible for small and medium farmers while preserving operational reliability. The hardware selection process was conducted based on cost, accuracy/performance, and maintenance difficulty. Table 1 summarizes the rationale for the selected hardware.

Table 1. Component selection and comparison matrix

Component	Option Considered	Cost (USD)	Performance / Accuracy	Reliability / Complexity	Rationale for Selection
Microcontroller	Arduino Mega 2560 (Selected)	Low (~\$15)	54 Digital I/O, 256KB Flash	High stability, easy maintenance	Chosen for its high I/O count to handle multiple fans/sensors without the OS overhead/complexity of a Raspberry Pi.
	Raspberry Pi 4	High (~\$55)	Multi-tasking OS, High processing	Complex (SD card corruption risk)	Overkill for simple control logic; higher power consumption and cost.
Temp/Hum Sensor	DHT22 / AM2302 (Selected)	Low (~\$4)	Temp: $\pm 0.5^{\circ}\text{C}$, Hum: $\pm 2-5\%$	Moderate (Good for standard condition)	Offers the best price-to-performance ratio. DHT11 is too inaccurate, while SHT31 is too expensive for multi-point deployment.
	DHT11	Very Low (~\$1)	Temp: $\pm 2^{\circ}\text{C}$, Hum: $\pm 5\%$	Low accuracy	Insufficient accuracy for monitoring heat stress risks in poultry.
	Industrial SHT31	High (~\$15)	Temp: $\pm 0.3^{\circ}\text{C}$, Hum: $\pm 2\%$	High	Too expensive for a scalable system targeting small-medium enterprises (SMEs).
Connectivity	ESP8266	Very Low (~\$2)	Wi-Fi 802.11 b/g/n	Moderate range	Sufficient for sending lightweight JSON data strings; extremely cost-effective compared to Zigbee/LoRa.
	ESP-01 (Selected)	Low (~\$2)	Wi-Fi 802.11 b/g/n	Moderate range	Sufficient for sending lightweight JSON data strings; extremely cost-effective compared to Zigbee/LoRa.

Environmental Sensors (DHT22): These sensors accurately measure temperature and humidity levels inside the closed environment. The data they collect is essential for maintaining optimal microclimate conditions and triggering ventilation or cooling actions as needed.

Water Flow Sensor (Raindrop Weather Module): This sensor monitors the functionality of the cooling pad system by detecting water presence and flow rates. Proper operation of the cooling system is crucial for maintaining lower internal temperatures during hot weather.

Safety Sensors (ME-8108 Limit Switches): Installed on exhaust fans and curtains, these sensors detect operational anomalies such as motor failures or improper curtain deployment. If an anomaly is detected, the system triggers an alert to prompt immediate corrective actions.

Communication Module (ESP-01 ESP8266 WiFi Module): This module enables the wireless transmission of sensor data and control signals to a cloud server, facilitating real-time monitoring and remote control through a mobile application.

Local User Interface (LCD Touchscreen): This interface provides on-site visualization and manual interaction capabilities for farm staff. It displays key metrics and allows manual automation overrides if necessary.

Each component is interconnected through a structured communication protocol managed by the microcontroller, ensuring seamless data flow and control operations. Data is acquired every 15 to 30 seconds, providing high-frequency updates that are essential for real-time decision-making. Figure 3 depicted the hardware used in hardware architecture.



Figure 3. Hardware specifications

Prototype

The integrated smart farm system was prototyped and installed in a real closed-house poultry farm with a population ranging from 3,000 to 5,000 laying hens. The evaluation covered hardware performance, system stability, farmer usability feedback, operational impact, and challenges faced during deployment. The design and development of smart closed-house hen farming using IoT technology is depicted in Figure 4.

The sensor placement uses a longitudinal gradient zoning method to capture the tunnel aeration dynamics of the 100 m x 13 m farm. Five AM2302 (DHT22) sensors were distributed along the cage to capture the thermal slope from the inlet to the exhaust. The placement logic is as follows:

Zone 1 (Inlet Area - 0m): To monitor the efficiency of the cooling pads.

Zones 2 and 3 (Intermediate—25 m & 50 m): To monitor the temperature in the middle of the cage.

Zone 4 (Rear - 75m): To detect heat accumulation before the exhaust area.

Zone 5 (Exhaust Area - 100m): To measure the maximum temperature before air extraction.

All sensors were mounted at a height of 50–60 cm from the ground (rather than in the ceiling) to represent the actual heat experienced by the hens. This configuration allows the system to calculate the average condition and identify specific zonal hotspots.

Temperature control: Average daily temperatures were successfully maintained within the thermoneutral zone (18°C–27°C) for 87% of monitored time, thanks to automated fan control and curtain activation based on real-time sensor readings. In hotter afternoons (30°C–32°C external temperature), internal temperatures rose slightly above 27°C for short periods, but automatic fan and cooling pad activation quickly reduced it back to 25–26°C within 15 minutes. The addition of cooling pad water flow monitoring ensured that evaporative cooling efficiency was sustained, reducing manual intervention needs.

Humidity Regulation: Humidity was more challenging to control, particularly during the rainy season. Recorded humidity levels exceeded the 70% threshold for 23% of the monitored time. Nevertheless, alarms and remote fan interventions helped mitigate prolonged high humidity conditions, reducing the risk of respiratory issues in hens.

Anomaly Detection: The ME-8108 limit switches on fans and curtains effectively detected mechanical failures (e.g., fan motor stoppages, curtain deployment errors). During testing, two instances of motor failure were successfully flagged via the system, prompting quick maintenance actions.

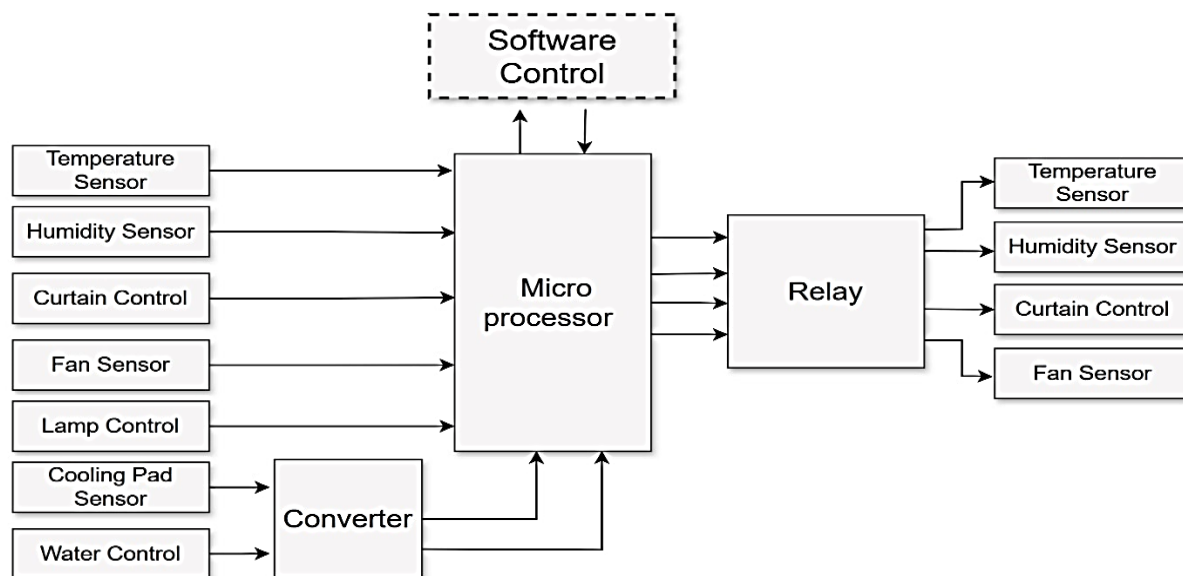


Figure 4. Smart closed-house farm management system: A schematic block diagram

Table 2. Truth table – warning system on IoT-based closed-house poultry farming

Temperature (°C)	Humidity (%)	Time	Condition	Cooling Fan	Curtain Action	Alert to Farmer
≤ 27	≤ 70	Anytime	Normal	OFF	Open	No
≤ 27	> 70	Anytime	Humidity High	ON	Open	No
> 27	≤ 70	Day	Temperature High	ON	Close	No
> 27	≤ 70	Night	Temperature High	ON	Open	No
> 27	> 70	Day	Temp & Humidity High (Risk Zone)	ON	Close	Yes
> 27	> 70	Night	Temp & Humidity High (Risk Zone)	ON	Open	Yes
< 18	Any	Day	Temperature Too Low (Risk Zone)	OFF	Close	Yes
< 18	Any	Night	Temperature Too Low (Risk Zone)	OFF	Close	Yes
Any	Any	Anytime	Fan/Curtain Mechanical Failure (Detected)	–	–	Yes (Maintenance)

*Day (6Am – 6 PM); Night (6 PM-6 AM)

To create optimal conditions for laying hens based on sensor input values (temperature and humidity), related time segments, environmental interpretation, system outputs (fan and curtain control), and related alerts. The environmental control and warning system settings in an IoT-based closed poultry farm are designed to perform settings such as whether temperature is above or below critical thresholds, whether humidity has exceeded risk levels, time of day (to adjust thermal regulation strategy), and control the mechanical integrity of actuators (fan and curtain via limit switch feedback). Based on these decisions, the system can dynamically activate or deactivate cooling fans, open or close cage curtains, trigger alarm systems, and send notifications to farmers or administrators, and it stores all critical events and conditions in a historical database, enabling post-event analytics and predictive maintenance. These settings can be seen in Table 2 and Figure 5. Additionally, Figure 6 describes the equipment communication schemes and flows and Figure 7. Illustrate the installed microcontroller.

Dashboard Design

A dashboard is a concise and visually appealing representation of critical information required to accomplish one or several objectives. It is designed to consolidate and organize this information on a single screen, allowing easy and quick monitoring [19], [20]. The dashboard demands careful execution and comprehension of the link between data type and display media when selecting visuals. Dashboards are commonly used in various fields and industries, such as business, finance, technology, and health, to give users a quick overview of key performance indicators (KPIs) or essential metrics. Dashboards provide efficient data representation in graphical form for managerial decision-making [21]. In shipping operation, creating dashboards provides optimized monitoring and control in real-time through graphs [22]. The use of technology such as dashboards to monitor the movement and behavior of laying hens can significantly improve the welfare and performance of chickens [23].

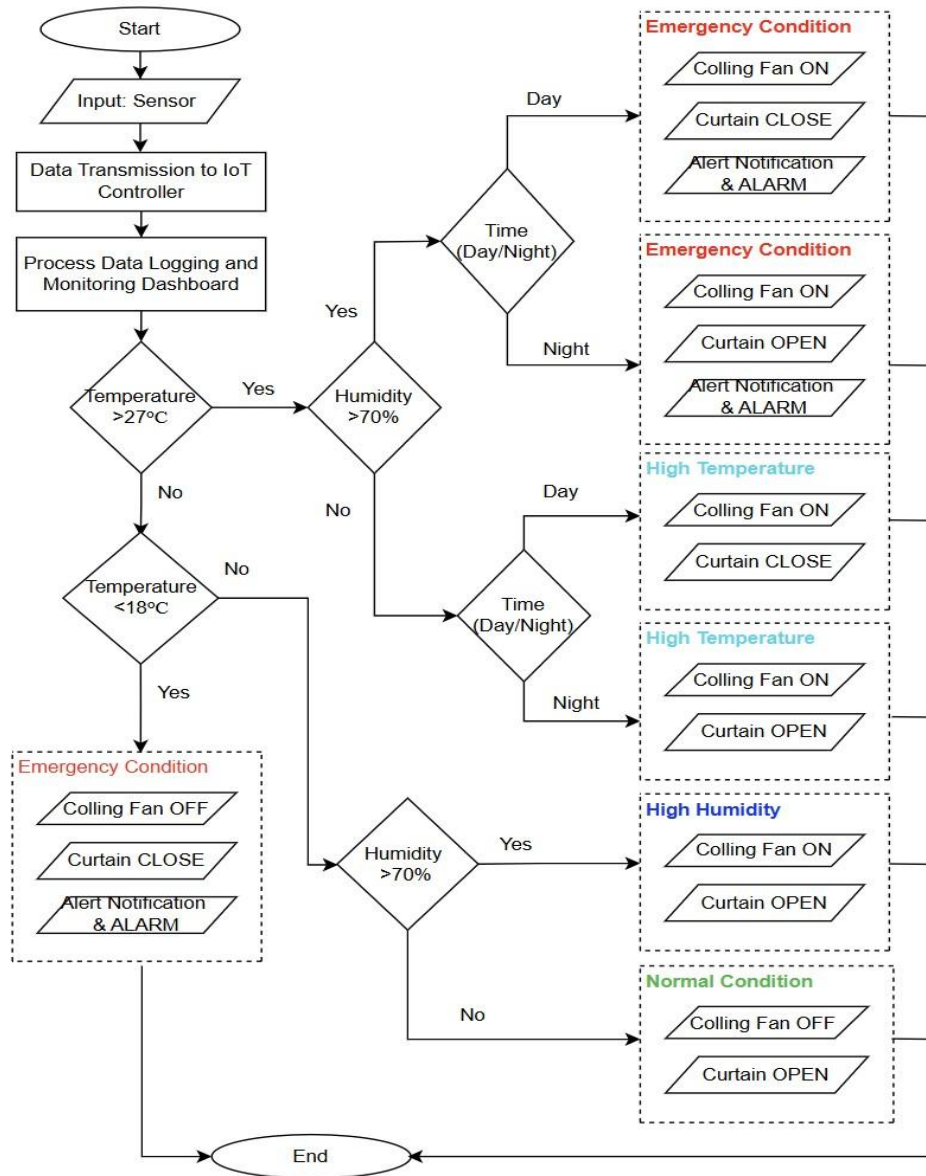


Figure 5. Flowchart warning system on IoT-based closed-house poultry farming



Figure 6. Equipment communication schemes and flows [18]

The dashboard and mobile application are essential components that connect farm operations with real-time monitoring, data visualization, and control capabilities. The system features a dual-dashboard structure along with an Android mobile application, ensuring easy access and improved decision-making for farmers.

Production Dashboard: This dashboard offers detailed insights into key production metrics. It displays Hen Day Egg Production (HDEP) and Hen House Production (HHP) values, which are critical indicators of flock performance. Trends in Feed Conversion Ratio (FCR) are visualized through dynamic charts, helping users assess feed efficiency. Additionally, average egg weights and mortality rates are tracked and presented in time-series graphs. HDEP is the total number of eggs produced on a day divided by number of hens present that day times 100%. While HHP is the total of eggs produced divided by number of initial hen times 100%. The FCR is calculated by comparing feed consumption (kg) with the quantity of eggs (kg) in a single cage, where a greater FCR when compared to existing cages indicates a good outcome [24]. Threshold indicators and color-coding (e.g., green for optimal performance and red for alerts) enable quick interpretation of the data.

Environmental Dashboard: This dashboard focuses on real-time environmental conditions on the farm, presenting data on temperature, humidity, fan operation status, lighting status, and cooling pad activity. Line graphs show environmental data over time, while alert mechanisms highlight any deviations from optimal ranges. Real-time averages are displayed alongside the maximum and minimum recorded values.

Mobile Application: The Android mobile application allows farmers to access farm data remotely. It includes features such as: (a) Real-time monitoring of temperature, humidity, and equipment status. (b) Remote control functions to activate or deactivate fans, lights, cooling pads, and curtains. (c) Instant push notifications for abnormal conditions (e.g., high temperature, sensor failures). (d) Historical data visualization with selectable time ranges (daily, weekly, monthly). (e) A user-friendly interface with intuitive navigation and multilingual support. (f) Manual override and automation reset capabilities for emergency management. The application architecture ensures that farmers can respond quickly, even from offsite, enhancing their responsiveness and operational flexibility. All collected data is securely stored on a cloud server, enabling advanced analytics for future farm optimization.

Results and Discussions

Data were collected from two distinct sources. The first data source comes from sensors installed on the enclosed farm, utilizing Arduino technology. The sensors capture the temperature, humidity, fan shutter, light, curtain, cooling pad, and water status. These sensors are updated at intervals of 15 seconds. The second pertains to the administration of the poultry farm, encompassing the monitoring of egg production and the overall well-being of the chickens. The second dataset was collected daily. These two datasets measure two separate characteristics of close-house farms; therefore, the dashboards cover both.

Dashboards

The first dashboard (Figure 7) consists of cards, a table, a line, and a pie chart. The cards display the number of productive, dead, and chickens that have stopped laying eggs. These numbers' percentages are depicted as a pie chart while the detail is summarized as a table. The line chart presents the trend of the egg weight. A calendar slicer is added for displaying the data daily.

The second dashboard (Figure 8) presents the egg production performance indicators, i.e., the HDEP, HHP, and FCR. HDEP measures the number of eggs each group of chickens produces at a certain age. For 24-week-old chickens, a good HEDP is in the range of 92-95% [8]. HHP measures the number of eggs produced within a certain period. HHP indicates the farm's ability to produce effective, high-quality, and profitable eggs from breeding layer-hens. A good HHP for laying hens is 90.3% [8]. The last indicator, FCR, can be used to describe the size of the feed efficiency in a livestock business. The smaller the FCR value, the higher the feed efficiency given to the chickens; a high level of feed consumption can cause high FCR while the total weight of eggs produced is low. In the second dashboard, three gauges are used to indicate whether the HEDP, HHP, and FCR have reached the targeted performance. Additionally, the HEDP and HHP cumulative charts indicate the weeks the targeted performance can be reached. A control chart that shows the upper control limit (UCL) and lower control limit (LCL) for FCR is also presented in this dashboard. It is 2.0 - 2.2 consecutively [8]. The third dashboard reporting the hen layer feeding process. It reports on the feed intake (Figure 9).

The fourth and fifth dashboards are mainly monitoring the temperature and humidity (Figure 10), The fans' status (Figure 11) and the lamp's status (Figure 12). The closed-house is divided into four sections. Each section has temperature and humidity sensors. The temperature and humidity dashboard presents the conditions in each section of the closed-house. However, in this paper we only present the average temperature and humidity

for the whole closed-house. It consists of two cards which summarize the average temperature and humidity, and two-line charts. The charts monitor the temperature and humidity every 15 seconds. It has upper and lower limits which indicate the ideal temperature and humidity for layer hens. The fourth and fifth dashboard summarized the utility of fans and lamps in the closed-house farm.



Figure 7. The chicks and eggs report



Figure 8. The eggs productions KPI



Figure 9. Feeding process

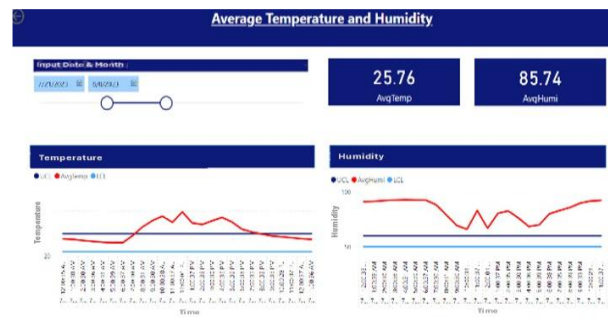


Figure 10. Average temperature and humidity in the close-house farm



Figure 11. The fans status



Figure 12. The lamps status

Since the experiment started the production performance has improved. The hen day production (HDP) increased from an average of 85% to 90–92% after three months of system use, indicating more stable laying performance. Hen house production (HHP) improved proportionally due to lower mortality rates (reduced by 1.5% over the trial period) and more consistent environmental control. Feed conversion ratio (FCR) FCR improved by 0.18 points, reflecting better feed efficiency and reduced wastage and the average egg weight stabilized within target standards (59–61 grams), reducing market rejection rates.

User Acceptance Testing

To test the feasibility of this IoT-based monitoring system application, User Acceptance Testing (UAT) was conducted, which aims to validate whether the monitoring system and real-time dashboard developed for closed-house chicken farms have met the requirements in terms of functionality and usability from the end user (farmer) perspective. This UAT focuses on evaluating the reliability, usability, and utility of the system in improving monitoring, decision-making, and operational efficiency (Table 3).

This UAT test was conducted on 15 recruited local poultry farmers. The participants varied in terms of experience, with 4 people having more than 10 years of experience in poultry farming, 6 people having between 5-10 years of experience, and 5 people having less than 5 years of experience. All participants managed small to medium-scale closed-house laying hen farms. The test was conducted for 2 weeks of continuous system usage.

Table 4 shows that the proposed IoT-based monitoring and dashboard system function well and is well received by users. Although there are some minor improvements and enhancements needed such as simplifying the icons on the application and real-time speed. This system is considered ready for wider use in commercial poultry farms. Its implementation can significantly improve operational visibility and decision making for egg production management. To provide a stronger viewpoint on the system's reliability see the pass rates in Table 4 for each test case scenario. Core functions such as real-time monitoring and remote control (TC1, TC3, TC4) achieved a 100% success rate. However, the evaluation identified minor latency in the alert trigger (TC2, 90%) and a need for better icon intuitiveness in the daily input interface (TC5, 80%), highlighting specific areas for future optimization

Table 3. User acceptance testing

Scenario ID	Test case	Expected outcome
TC1	Monitor temperature and humidity via dashboard	Accurate real-time data displayed
TC2	Trigger system alert when upnormal/risk zone condition, fan failure, and curtain failure is simulated	Alarm and dashboard warning activated
TC3	View Hen Day Production (HDP) and Feed Conversion Ratio (FCR)	Metrics updated daily on dashboard
TC4	Remotely open/close curtain based on sensor values	Curtain status change confirmed visually and via sensor
TC5	System usability for daily record entry	Farmers able to input daily production values without assistance

Table 4. UAT result

Scenario ID	Pass rate	Notes
TC1	100%	Data reflected correctly within 4 - 7 seconds
TC2	90%	One case failed due to delayed alert trigger
TC3	100%	Metrics displayed correctly and understood by users
TC4	100%	Remote control via dashboard worked reliably
TC5	80%	Some farmers requested more intuitive icons

System Usability Score (SUS): 78.5

Average Farmer Satisfaction: 4.4 / 5.0

Managerial Insight

In the first dashboard, the management can get insight into the chicken statistics on the farm and the trend of the egg weight. In the depicted situation, the trend of the daily average of the egg weight is increasing. However, the maximum weight of the current egg, i.e., 60 grams, is below the standard weight of purebred chicken eggs, i.e., 62.5 grams. Meanwhile, the management could monitor the targeted egg production performance through the second dashboard. Currently, the HDP is only 89.68% of 95%; the HHP is 88.71% of 93%, and the FCR is highly above the UCL and LCL. The dashboard suggests that the management should optimize farm management to reach the targeted performance.

The temperature and humidity in the closed house can be monitored every 15 seconds since the dashboard is connected to the sensors in real time. The poultry management can handle the current situation when the temperature and humidity are outside the UCL and LCL. For example, Figure 5 shows that the temperature and humidity are outside the UCL and LCL; the average temperature is 25.60, and the average humidity is 79.8. Laying hens exposed to a temperature in the environment above the thermoneutral zone will experience heat stress, which triggers the mechanisms of physiological defenses such as panting [9], [11]. Fans, lamps, and cooling pads are instruments used in the closed house to control the temperature and humidity of the closed house. Poultry management can improve the utilization of those instruments.

Several operational challenges need to be addressed, including network stability, humidity control during the rainy season, and energy consumption. Firstly, network stability is a concern, as Wi-Fi often experiences interruptions due to fluctuations in signal strength in rural areas, which can hinder data transmission. Future versions of the system could incorporate LTE or 5G modules or include local server fallback options to enhance

connectivity. Secondly, the current ventilation systems struggle with high humidity levels in external air during the rainy season, making humidity control difficult. To tackle this issue, future designs may need to incorporate additional dehumidification strategies, such as heating elements or chemical drying methods.

The implementation of an IoT system presents a trade-off between increased utility costs and efficiency gains. Using fans and a cooling system to maintain the cage temperature generates an estimated 8-10% increase in electricity consumption. On the other hand, the FCR improves by 0.18 points (from ~2.28 to ~2.10). In the context of poultry farming, where feed costs naturally represent 60–70% of total production expenses, this efficiency gain is substantial. A 0.18-point reduction in FCR implies a significant decrease in the amount of feed required to produce a kilogram of eggs, which, combined with the 1.5% reduction in mortality rates, creates a surplus that surpasses the increase in the cost of electricity. Also, the HDP at 90–92% guarantees a consistent revenue income. Therefore, the analysis confirms that the system achieves a positive Return on Investment (ROI) by shifting costs from "waste" (inefficient feed usage and high mortality rate) to "control" (energy).

System Limitations and Redundancy Measures

Although the system demonstrated functional success, long-term industrial implementation requires addressing specific limitations. Primarily, the cost-effective AM2302 sensors are vulnerable to accuracy drift due to dust and ammonia accumulation, so a regular calibration schedule is needed to maintain data integrity. Additionally, to mitigate the risk of unstable internet connectivity in rural areas, the system combines a local redundancy strategy. Fan and curtain control is executed locally by the Arduino, ensuring independent environmental regulation. Moreover, manual override switches are installed as a final fail-safe against system failure.

Conclusions

The proposed IoT-based monitoring and dashboard system represents a substantial technical leap in the modernization of poultry farm operations. By enabling real-time decision support and environmental control, the system not only enhances production performance but also paves the way for scalable, data-driven agricultural solutions. By utilizing advanced sensor technology and microcontroller platforms, the system provides continuous oversight of critical environmental factors such as temperature, humidity, and ventilation, ensuring optimal conditions for laying hens.

A detailed evaluation of key performance metrics, including Hen Day Production (HDP), Hen House Production (HHP), and Feed Conversion Ratio (FCR), demonstrates the system's practical value in enhancing operational efficiency and supporting informed decision-making.

The integration of an Android-based dashboard allows for timely interventions and simplifies the overall management process for poultry farmers by presenting complex data in an accessible format. Practical testing with local poultry farmers has confirmed improvements in monitoring capabilities, usability, and overall farm management efficiency, highlighting the potential to significantly boost productivity and animal welfare.

While some limitations were noted—reflecting challenges inherent in deploying such technologies under variable real-world conditions, the system's potential to transform closed-house poultry operations is evident. Future work aimed at refining sensor accuracy, expanding the range of monitored parameters, and integrating advanced analytics will further enhance the tool's effectiveness, leading to more sustainable and resilient poultry production practices.

In summary, the deployment of this integrated IoT monitoring solution represents a promising step toward more innovative, data-driven agricultural practices that can reliably improve farm productivity and animal care in the dynamic environment of closed-house poultry farming.

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