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IoT-Based Poultry Farm Automation System for Heat Stress Mitigation and Environmental Monitoring

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Abstract

Purpose: This study aimed to develop an Internet of Things (IoT)-based Smart Poultry system for monitoring and controlling poultry house conditions in tropical environments. The system was designed to reduce heat stress and improve poultry welfare, health, and productivity through automated environmental management.

Research Methodology: The study was conducted from October 2023 to March 2024 at the Integrated Field Laboratory, Universitas Lampung. The prototype integrated multiple sensors (DHT22, MLX90614, BMP388, ENS160, and MQ137) with an ESP32 microcontroller. PCB design was developed using DipTrace, firmware was programmed in Arduino IDE, cloud monitoring was implemented through ThingSpeak, and a mobile monitoring application was created using Android Studio.

Results: The Smart Poultry prototype successfully monitored body temperature, ambient temperature, humidity, atmospheric pressure, air quality, and ammonia concentration in real time. PCB redesign was required to correct connectivity issues and reduce manufacturing costs through the adoption of a single-layer board configuration.

Conclusions: The developed system demonstrated the feasibility of a low-cost and scalable IoT solution for automated poultry house monitoring and environmental control in tropical farming conditions.

Limitations: Testing was performed in a simulated laboratory environment, and long-term reliability under commercial farm conditions was not evaluated.

Contributions: This study contributes a practical multisensor IoT framework for smart poultry farming and provides guidance for implementing precision livestock management systems in developing countries.

Keywords: *DHT22, ESP32, IoT, Poultry Automation, Smart Farming*

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1. Introduction

Poultry farming constitutes one of the most economically significant sectors within global food production systems, providing a primary source of animal protein through both meat and eggs. Indonesia, as a tropical archipelago nation, has witnessed rapid expansion in its broiler and layer industries; however, the unique climatic conditions of the region pose persistent challenges to production efficiency and animal welfare (Lara & Rostagno, 2023). Among the most critical threats to poultry health in tropical environments is heat stress, a physiological condition arising from the inability of birds to dissipate body heat when ambient temperatures exceed Their Thermoneutral Zone (TNZ).

Chickens are highly susceptible to thermal fluctuation. The optimal core body temperature for healthy broiler chickens ranges between 39.9 and 41°C, and mortality risk increases substantially when body temperature exceeds 41°C (Zaboli, Slimen, Triga, & Capozzi, 2021). Sustained exposure to elevated ambient temperatures triggers a cascade of physiological responses, including reduced feed intake, elevated respiratory rate, immunosuppression, and compromised reproductive performance (St-Pierre, Cobanov, & Schnitkey, 2023). These effects translate directly into significant economic losses, particularly in terms of reductions in growth rate, egg production, meat quality, and eggshell integrity, as well as increased flock mortality (Liu, Xue, Wang, & Zhang, 2022).

Conventional poultry farm management in Indonesia and similar developing nations relies heavily on manual labor for environmental monitoring, which is labor-intensive and prone to delayed responses. The adoption of digital technologies in the agricultural sector, collectively termed Agriculture 4.0, presents transformative opportunities for automating routine monitoring and control functions (Walter, Finger, Huber, & Buchmann, 2017). The Internet of Things (IoT) paradigm, which enables physical devices embedded with sensors and actuators to communicate over Internet protocols, has emerged as a particularly promising framework for smart livestock management (Astill, Dara, Fraser, Roberts, & Sharif, 2020).

Precision Livestock Farming (PLF) represents the practical application of the IoT and advanced sensing technologies to continuously monitor individual and group-level animal indicators, thereby enabling data-driven decision-making in farm management (Neethirajan, 2020). Prior studies have demonstrated the utility of sensor-based systems for monitoring temperature, humidity, ammonia concentration, and feed consumption in poultry facilities (Choukidar & Dawande, 2017; Enriko et al., 2021). However, several research gaps still remain. First, most existing systems are designed for temperate climates and may not account for the compounding effects of high humidity and elevated temperatures characteristic of tropical settings. Second, multi-sensor fusion approaches that simultaneously track both individual animal body temperatures and ambient environmental parameters within a unified platform remain unexplored. Third, the cost-effectiveness and hardware simplicity of the proposed systems remain barriers to adoption among smallholder farmers, who represent the majority of Indonesian poultry producers.

This study addresses these gaps by developing a multi-sensor IoT-based automation prototype, designated Smart Poultry, which integrates infrared thermometry, atmospheric sensing, air quality monitoring, and gas detection capabilities within a single ESP32 microcontroller platform. The system employs real-time cloud data transmission via ThingSpeak and mobile application monitoring via Android Studio to provide remote surveillance of the farm. The primary research objectives were as follows: (1) to design and implement a multi-sensor PCB-based hardware prototype for continuous environmental monitoring in chicken coops; (2) to evaluate the functional performance of individual sensor modules under simulated poultry farm conditions; and (3) to assess the system's capacity for real-time data acquisition, transmission, and remote monitoring.

The novelty of this research lies in the simultaneous integration of non-contact infrared individual chicken body temperature sensing with ambient environmental monitoring, a combination not widely reported in the literature for low-cost IoT applications in tropical settings. The remainder of this paper is structured as follows: Section 2 reviews the relevant theoretical and empirical literature. Section 3 describes the research methodology used in this study. Section 4 presents and discusses the results of the study. Section 5 draws conclusions, identifies limitations, and proposes directions for future research.

2. Literature Review

2.1 Heat Stress in Poultry: Mechanisms and Consequences

Heat stress in poultry occurs when the sum of metabolic heat production and absorbed environmental heat exceeds the animal's capacity for heat dissipation (Lara & Rostagno, 2023). At the cellular level, heat stress activates heat shock proteins, impairs mitochondrial function, and disrupts intestinal barrier integrity, resulting in an increased susceptibility to bacterial translocation and systemic inflammation (Zaboli, Slimen, Triga, & Capozzi, 2021). At the production level, comprehensive meta-analyses have documented reductions in broiler growth rates of 10–25% and a decrease in layer egg production of 15–30% during heat stress episodes (Liu et al., 2022; St-Pierre et al., 2023). The multidimensional nature of heat stress impacts encompassing health, welfare, and economic dimensions underscores the urgency of effective monitoring and mitigation strategies.

2.2 IoT and Precision Livestock Farming

The IoT ecosystem for agriculture integrates physical sensing hardware, wireless communication networks, cloud computing platforms, and user-facing applications into a cohesive data pipeline (Walter, Finger, Huber, & Buchmann, 2017). Astill et al. (2020) conducted a systematic review of smart poultry management technologies and identified sensor networks, automated feeding systems, and predictive analytics as the three primary technological domains within PLF. Their analysis highlighted that while technological capabilities for smart poultry management exist, adoption barriers, including cost, technical complexity, and unreliable rural Internet connectivity, continue to impede widespread implementation, particularly in the Global South.

Microcontroller platforms have undergone rapid development in the sensor technology domain. The ESP32, a dual-core 32-bit processor with integrated WiFi and Bluetooth capabilities developed by Espressif Systems, has emerged as a dominant platform for IoT prototyping because of its low cost, high processing capacity, and versatile General Purpose Input/Output (GPIO) interfaces (Babiuch, Foltýnek, & Smutný, 2019). Multiple studies have validated the ESP32 for agricultural sensing applications, demonstrating its reliable operation in humidity-rich, electrically noisy farm environments (Enriko et al., 2021; Kasakula et al., 2021).

2.3 Environmental Sensing Technologies for Poultry Applications

The DHT22 (also designated AM2302) is a capacitive humidity and resistive temperature sensor offering a temperature range of −40°C to +80°C with ±0.5°C accuracy and a humidity range of 0–99.9% RH with ±2–45% accuracy (Aosong, 2020). Its digital single-bus interface simplifies the microcontroller integration. Comparative studies have validated the DHT22 against laboratory-grade thermohygrometers, confirming its adequate accuracy for ambient farm monitoring (Rahayu, Kusuma, & Widyastuti, 2020).

The MLX90614 is a non-contact infrared thermometer manufactured by Melexis that can measure object temperatures in the range of −70°C to +380°C with a resolution of 0.02°C. Its I2C interface and factory calibration make it suitable for individual animal temperature screening without physical contact, which is an important welfare consideration in poultry contexts (Melexis, 2019). The BMP388, a high-accuracy barometric pressure sensor from Bosch Sensortec, provides atmospheric pressure measurements with an absolute accuracy of ±0.5 hPa and a resolution of 0.016 Pa, which is useful for altitude compensation and weather trend monitoring (Bosch, 2020).

Gas monitoring within poultry facilities is critical, given the documented welfare and health impacts of ammonia accumulation. Ammonia concentrations exceeding 25 ppm have been associated with ocular and respiratory pathologies in broilers (Choukidar & Dawande, 2017). The MQ137 electrochemical sensor provides a detection range of 5–500 ppm for ammonia gas, thereby enabling threshold-based automated ventilation control (Winsen, 2015). The ENS160, a multi-gas sensor from ScioSense that measures Total Volatile Organic Compounds (TVOCs) and CO_2 equivalents, provides complementary air quality indices to support comprehensive indoor air quality assessment (ScioSense, 2020).

2.4 Existing Smart Poultry Systems: A Critical Review

Several studies have developed and evaluated IoT-based poultry monitoring systems. Choukidar and Dawande (2017) implemented a wireless sensor network using GPRS communication to monitor temperature, humidity, water levels, and gas concentration, with a Raspberry Pi as the central processing unit and a web interface for remote access. Although their system demonstrated functional capability, the use of GPRS technology presents latency and cost disadvantages compared with modern Wi-Fi and MQTT-based architectures.

Enriko et al. (2021) developed an automatic temperature control system specifically for smart poultry applications using IoT, demonstrating automated fan and heater control based on DHT22 sensor feedback. However, their study did not incorporate individual animal body temperature monitoring or multi-gas sensing capabilities. Kasakula et al. (2021) proposed a temperature and humidity control algorithm for poultry farm systems but primarily focused on control logic design rather than hardware implementation. Srithorn et al. (2019) developed a real-time environmental monitoring system for Thai poultry farms; however, their work did not address ammonia gas monitoring or infrared body temperature measurement.

A recent study by Khan et al. (2022) developed a smart automation system for controlling environmental parameters in poultry farms to increase production, demonstrating the automated control of ventilation and heating systems. Their research represents a significant advance; however, it was conducted in a temperate climate context and did not employ non-contact body temperature sensing methods. The present study builds upon these foundations by addressing the identified gaps through multi-sensor fusion in tropical settings.

2.5 Theoretical Framework

The theoretical underpinning of this study integrates two conceptual frameworks. First, the Cyber-Physical Systems (CPS) framework conceptualizes the integration of computational intelligence with physical processes through sensing, actuation, and networked communication Walter et al., 2017. The Smart Poultry system instantiates this framework by creating a closed-loop system in which environmental sensor data trigger automated actuator responses. Second, the Animal Welfare Science framework emphasizes that minimizing stress exposure is both ethically imperative and economically rational, as stress-free animals demonstrate superior productivity efficiency Neethirajan, 2020. Therefore, the automation of environmental regulation serves simultaneously as a welfare intervention and a production optimization strategy.

3. Research Methodology

3.1 Research Design and Setting

This study adopted a design-and-build experimental methodology involving iterative design, prototype fabrication, and functional testing. The study was conducted from October 2023 to March 2024 at the Integrated Field Laboratory of the Faculty of Agriculture, Universitas Lampung, Bandar Lampung, Indonesia. A simulated poultry coop environment was established to enable the controlled testing of the prototype system.

The design-and-build approach was selected because it facilitates the systematic development and evaluation of technological prototypes in real-world-inspired settings (Ren, Duhatschek, Bartolomeu, Erickson, & Giordano, 2023). Through iterative cycles of design, implementation, testing, and refinement, potential hardware and software issues could be identified and addressed progressively throughout the development process. This methodology enabled the researchers to assess not only the technical feasibility of the proposed system but also its operational performance under controlled environmental conditions before considering broader field deployment ((Prasanna, 2021); (Anas, Singh, & Kamarudin, 2022)).

The use of a simulated poultry coop environment provided a practical and safe platform for prototype validation. Controlled testing conditions allowed environmental variables such as temperature and air quality to be manipulated systematically, enabling the observation of sensor behavior and actuator responses under different scenarios (Kaur, Malacco, Bai, Price, Datta, Xin, Sen, Nawrocki, Chiu, Sundaram, Min, Daniels, White, Donkin, Brito, & Voyles, 2023). This approach improved the repeatability of experimental procedures and reduced external sources of variability that might otherwise influence the evaluation results. Consequently, the testing environment provided a reliable basis for assessing the functionality, responsiveness, and integration of the Smart Poultry monitoring and control system ((Shafie, Zainab, Adam, & Azizan, 2022); (Aleluia, Soares, Caldeira, & Gaspar, 2023)).

3.2 System Architecture

The Smart Poultry system architecture consists of three layers: (1) sensing and actuation hardware layer, (2) microcontroller processing layer, and (3) cloud communication and user interface layer. The hardware layer comprises multiple sensor modules and actuators connected to custom PCB. The processing layer uses the ESP32 microcontroller (DFRobot type dfrobot0654) as the central computational unit. The communication layer transmits the processed data to the ThingSpeak cloud IoT platform via Wi-Fi using the MQTT protocol, and a custom Android application developed in Android Studio provides real-time mobile monitoring (Shabani, Biba, & Çiço, 2022; Wan, Zhao, Lu, Li, Lu, & Wang, 2022).

The layered architecture was designed to promote modularity, scalability, and ease of maintenance. By separating sensing, processing, and communication functions into distinct layers, the system allows individual components to be modified or upgraded without requiring substantial changes to the overall architecture. For example, additional sensors can be incorporated into the hardware layer, while alternative cloud platforms or mobile applications can be integrated into the communication layer with minimal impact on the core processing logic. This modular design approach enhances system flexibility and supports future expansion as monitoring requirements evolve (Arcidiacono, Pastell, & Cascone, 2023; Wan et al., 2022).

Furthermore, the integration of cloud connectivity and mobile access significantly improves the accessibility of environmental and animal health information for poultry farmers. Real-time data transmission to the ThingSpeak platform enables continuous monitoring, historical data storage, and remote access to key performance indicators (Jain, Bhatla, Kikani, Joshi, & Patel, 2023). The Android application further enhances usability by presenting sensor readings and system status information through a mobile interface, allowing users to monitor coop conditions regardless of their physical location. This combination of IoT communication technologies and mobile monitoring capabilities supports more informed decision-making and contributes to the advancement of smart poultry farming practices (Ezema, Ifediora, Olukunle, & Onuekwusi, 2021; Kaur, Malacco, Bai, Price, Datta, Xin, Sen, Nawrocki, Chiu, Sundaram, Min, Daniels, White, Donkin, Brito, & Voyles, 2023).

3.3 Hardware Components

The Smart Poultry prototype integrates a multi-sensor suite designed to monitor environmental conditions and animal health within the poultry house. The DHT22 (AM2302) sensor was used to measure ambient temperature and relative humidity, offering a measurement range of −40°C to +80°C with an accuracy of ±0.5°C. Individual chicken body temperature was monitored using the MLX90614 non-contact infrared thermometer, which provides an object temperature measurement range of −70°C to +380°C with a resolution of 0.02°C. Atmospheric pressure data were collected using the BMP388 digital barometric pressure sensor, which offers an absolute accuracy of ±0.5 hPa and supports altitude compensation. Air quality monitoring was performed using the ENS160 multi-gas sensor, capable of measuring Total Volatile Organic Compounds (TVOC) and carbon dioxide equivalents (eCO_2), while ammonia concentration was detected using the MQ137 gas sensor with a detection range of 5–500 ppm. The integration of these sensors enabled comprehensive monitoring of environmental and physiological parameters relevant to poultry welfare and production performance.

To support environmental control functions, the prototype employed three actuators consisting of a ventilation fan, an infrared heating lamp, and a water pump. All actuators were controlled through an 8-channel 5V optically isolated relay module, ensuring safe electrical isolation between the control circuitry and the power-driven devices. The central processing unit of the system was the ESP32 microcontroller, which features 34 programmable GPIO pins, dual-core processing at 240 MHz, and integrated IEEE 802.11 b/g/n Wi-Fi connectivity. These capabilities enabled efficient sensor data acquisition, local processing, wireless communication, and real-time actuator control within a single embedded platform. Together, the sensor network, actuator modules, and ESP32 controller formed an integrated Smart Poultry system capable of automated environmental monitoring and responsive management of poultry house conditions.

3.4 PCB Design and Fabrication

The circuit schematic design and PCB layout were performed using DipTrace software, which was selected for its suitability for educational and prototyping contexts. The initial design employed a dual-layer PCB; however, upon fabrication quotation, cost constraints necessitated a redesign to a single-layer configuration. The revised single-layer PCB maintained all functional connectivity while reducing the fabrication costs. The components were mounted and soldered manually following the standard PCB assembly procedures. After soldering, the PCB underwent visual and electrical continuity inspections prior to firmware flashing.

The transition from a dual-layer to a single-layer PCB configuration represents an important design consideration in terms of cost efficiency and practical implementation. Although dual-layer boards generally provide greater routing flexibility and improved signal management, the single-layer redesign successfully preserved the required electrical connections and system functionality while significantly reducing manufacturing expenses. This design decision is particularly relevant for prototype development and small-scale agricultural technology applications, where affordability is often a critical factor influencing adoption. The resulting PCB demonstrates that functional IoT monitoring systems can be implemented using cost-effective hardware architectures without compromising core operational capabilities.

Following assembly, comprehensive inspection procedures were conducted to ensure hardware reliability before system deployment. Visual inspection was used to identify potential soldering defects, component placement errors, or unintended short circuits, while continuity testing verified the integrity of electrical connections throughout the board. These verification steps were essential for minimizing hardware-related failures during subsequent firmware installation and system testing. By combining careful PCB design, cost-conscious fabrication decisions, and systematic quality assurance procedures, the development process established a stable hardware foundation for the Smart Poultry monitoring and control platform.

3.5 Firmware Development and Data Transmission

The firmware was developed using the Arduino IDE (version 2.x) with the official ESP32 board support package. The sensor libraries employed included the Adafruit DHT sensor library, MLX90614 library by SparkFun, BMP3XX library by Adafruit, and ScioSense ENS160 library. The firmware logic followed a polling-based architecture: sensor readings were sampled at 5-second intervals, processed locally on the ESP32, and transmitted to ThingSpeak via HTTP GET requests over Wi-Fi. Actuator control thresholds were programmed based on published optimal poultry coop parameters: temperature >30°C triggered fan activation, temperature <20°C triggered heater activation, and ammonia concentration >25 ppm triggered forced ventilation.

The adoption of a polling-based firmware architecture provided a straightforward and reliable mechanism for coordinating sensor acquisition, data processing, cloud communication, and actuator control. By sampling environmental parameters at fixed five-second intervals, the system maintained a balance between monitoring responsiveness and computational efficiency. This approach ensured that sensor data remained sufficiently current for real-time decision-making while minimizing unnecessary processor utilization and network traffic. The local processing capability of the ESP32 also reduced dependence on external servers for immediate control actions, allowing critical environmental responses to be executed without significant delays.

Furthermore, the use of widely adopted open-source libraries enhanced the portability, maintainability, and reproducibility of the system. Each library provided standardized interfaces for sensor communication, simplifying firmware development and reducing the likelihood of implementation errors. The threshold-based control strategy was designed to maintain environmental conditions within ranges considered suitable for poultry health and productivity. Through continuous monitoring and automated actuation, the firmware enabled proactive environmental management, helping to mitigate the adverse effects of heat stress, cold stress, and poor air quality. This integration of sensing, communication, and automated control demonstrates the practical applicability of low-cost IoT technologies for precision livestock farming and smart agricultural monitoring systems.

3.6 Testing and Validation Procedure

The testing procedure was based on a structured three-phase approach. Phase 1 (Simulation Testing) evaluated the circuit schematic for logical errors using DipTrace built-in electrical rules check (ERC). Phase 2 (Bench Testing) verified the individual sensor functionality and I^2C/SPI address conflicts following PCB assembly. Phase 3 (Integrated System Testing) assessed end-to-end data acquisition, transmission to ThingSpeak, and actuation response under simulated environmental conditions in a laboratory setting.

Moreover, the multi-phase testing methodology ensured that potential hardware and software issues were identified and resolved progressively before full system integration. The simulation testing phase provided an initial validation of circuit integrity and component connectivity, minimizing the risk of design errors prior to PCB fabrication. Subsequently, bench testing enabled the verification of sensor calibration, communication stability, and address allocation across interconnected devices. This staged validation approach reduced troubleshooting complexity and increased confidence in the reliability of the assembled prototype before it was subjected to integrated operational testing.

The integrated system testing phase further evaluated the interoperability of all system components under realistic operating scenarios. Data generated by the environmental and physiological sensors were successfully transmitted to the ThingSpeak cloud platform, where real-time monitoring and visualization could be performed. Simultaneously, the actuator control mechanisms responded appropriately to predefined environmental thresholds, demonstrating the effectiveness of the end-to-end sensing, communication, and control workflow. These results indicate that the proposed Smart Poultry architecture is capable of supporting continuous environmental monitoring and automated intervention, forming a solid foundation for future deployment in practical poultry farming environments.

4. Results and Discussions

4.1 PCB Design Iteration and Connectivity Resolution

The initial PCB schematic design revealed a critical connectivity error between the ESP32 microcontroller and the peripheral sensor components. Specifically, the I^2C bus lines (SDA and SCL) were incorrectly routed, preventing communication with the MLX90614, BMP388, and ENS160 sensors of the device. This error was identified during the DipTrace ERC simulation phase and corrected prior to PCB fabrication, demonstrating the value of pre-fabrication schematic validation in reducing the development costs.

The revised schematic successfully mapped all the sensor and actuator connections to the appropriate GPIO pins on the ESP32, thereby resolving the identified connectivity issues. Subsequently, the initial dual-layer PCB design was redesigned as a single-layer board to address fabrication cost constraints. The redesign required the strategic rerouting of several signal traces and the introduction of solder-bridge jumpers at three crossover points. The final single-layer design achieved full functional equivalence with the original dual-layer concept at a significantly reduced fabrication cost, making the design more accessible for small-scale deployment.

The progression from the initial to the revised PCB design illustrates the iterative prototyping process inherent in the development of embedded systems. Similar iterative hardware refinement processes have been reported by Babiuch et al. (2019) in ESP32-based data processing systems and by Enriko et al. (2021) in smart poultry temperature control prototypes, thus validating the methodology employed in this study.

4.2 Sensor Performance and Data Acquisition

Following the PCB assembly and firmware flashing, all five sensor modules demonstrated successful initialization and data output. The DHT22 sensor produced stable ambient temperature readings within the expected range for the laboratory environment (24–28°C), with readings consistent with those of a calibrated reference thermometer. The MLX90614 infrared sensor successfully captured surface temperature measurements at a distance of 5–15 cm within the sensor's optimal field-of-view cone angle. These readings are particularly significant as they represent the non-contact individual chicken body temperature monitoring capability, which distinguishes this system from many prior implementations.

The BMP388 sensor provided continuous atmospheric pressure readings at a resolution consistent with the specifications of the data sheet. The ENS160 sensor, following a mandatory warm-up period of approximately 3 min, as specified in the datasheet, produced stable TVOC and eCO_2 readings. The MQ137 ammonia sensor demonstrated sensitivity to trace ammonia levels introduced during controlled testing, outputting voltage readings that were converted to ppm using the calibration curve specified in the manufacturer's datasheet.

Real-time data from all sensors were successfully transmitted to the ThingSpeak platform, where time-series visualizations confirmed continuous data streams without transmission dropouts during bench testing. The Android application successfully retrieved and displayed live sensor data from the ThingSpeak API, thereby confirming the end-to-end system functionality. These results align with the findings of Astill et al. (2020) regarding the feasibility of IoT sensor networks for smart poultry management and extend previous single-sensor studies by demonstrating simultaneous multi-sensor data fusion.

4.3 Actuator Control Functionality

The relay module demonstrated reliable control of all three actuators, namely the ventilation fan, heater, and water pump, based on predefined environmental threshold conditions. Experimental testing showed that the system was capable of autonomously responding to changing environmental parameters without requiring manual intervention. When the ambient temperature was intentionally increased above the predefined threshold of 30°C using an external heat source, the control algorithm detected the change and activated the ventilation fan automatically. The observed response latency was consistently below two seconds, indicating that the system can provide near real-time environmental regulation. Such responsiveness is essential in poultry farming applications, where prolonged exposure to excessive temperatures may negatively affect animal welfare, feed consumption, and productivity.

Similarly, the heating mechanism functioned according to the programmed control logic when environmental temperatures dropped below the lower threshold of 20°C. Under these conditions, the relay module successfully activated the heater to restore a more suitable thermal environment within the poultry enclosure. In addition to temperature management, the system effectively responded to deteriorating air quality conditions. The ammonia-based ventilation mechanism was validated by introducing a controlled ammonia source near the MQ137 sensor. Once the measured ammonia concentration exceeded the specified threshold, the system automatically activated the ventilation fan to improve air circulation and reduce the accumulation of harmful gases. These results confirm the effectiveness of the sensor-actuator integration and demonstrate the capability of the proposed platform to support automated environmental management within poultry housing systems.

The automated control responses observed in this study are consistent with previous IoT-based poultry monitoring and environmental control systems. Earlier studies have demonstrated the effectiveness of automated temperature and humidity regulation for maintaining optimal poultry house conditions and reducing the need for continuous manual supervision. However, the present implementation extends beyond conventional environmental monitoring by incorporating a non-contact body temperature sensing capability through the MLX90614 infrared sensor. This additional functionality enables direct monitoring of animal physiological conditions alongside environmental parameters, providing a more comprehensive assessment of poultry welfare. Consequently, the proposed Smart Poultry system not only supports environmental control but also introduces an additional layer of health surveillance that may facilitate earlier detection of stress-related conditions and improve overall farm management practices.

4.4 Comparative Analysis with Prior Systems

Table 1. Comparative Analysis of IoT-Based Poultry Monitoring Systems

Feature	Choukidar & Dawande (2017)	Enriko et al. (2021)	Khan et al. (2022)	Present Study
Microcontroller	Raspberry Pi	ESP32	Arduino/ESP	ESP32 (DFRobot)
Communication	GPRS	Wi-Fi	Wi-Fi	Wi-Fi/MQTT
Ambient Temp/Humidity	✓	✓	✓	✓
Non-contact Body Temp	✗	✗	✗	✓
Ammonia Gas Sensing	✓	✗	✗	✓
Air Quality (TVOC)	✗	✗	✗	✓
Atmospheric Pressure	✗	✗	✗	✓
Cloud Platform	Web Server	ThingSpeak	Custom	ThingSpeak
Tropical Climate	No	Yes	No	Yes

Table 1 compares the proposed Smart Poultry system with several existing IoT-based poultry monitoring solutions reported in previous studies. The comparison highlights differences in hardware architecture, communication technologies, sensing capabilities, cloud integration, and deployment context. Similar to earlier systems, the proposed prototype utilizes an ESP32-based microcontroller and supports ambient temperature and humidity monitoring. However, the system extends the functionality of previous implementations through the integration of additional environmental and animal welfare sensors, including non-contact body temperature measurement, ammonia gas detection, air quality monitoring (TVOC), and atmospheric pressure sensing. These sensing capabilities provide a more comprehensive assessment of poultry house conditions and animal well-being than systems that focus solely on environmental monitoring.

The comparison further demonstrates several technological advantages of the proposed implementation. Unlike the system developed by Choukidar and Dawande (2017), which relied on GPRS communication, the present study employs Wi-Fi and MQTT protocols, enabling more efficient and scalable real-time data transmission. Compared with (Enriko, Rizqiawan, & Effendi, 2021), the inclusion of the MLX90614 non-contact infrared temperature sensor introduces an additional animal health monitoring dimension by allowing body temperature measurement without physical contact. Moreover, while (Khan, Masood, Hussain, & Khan, 2022) implemented a Wi-Fi-based monitoring platform, the present system incorporates a broader range of sensing modalities and was specifically designed and evaluated for tropical environmental conditions. Collectively, these characteristics indicate that the proposed Smart Poultry system offers a more integrated and comprehensive IoT monitoring framework for poultry farming applications.

4.5 Limitations of the Current Implementation

The limitations of the current prototype must be acknowledged. First, all tests were conducted in a simulated laboratory environment, which may not fully replicate the electromagnetic noise, dust, and moisture challenges of an operational poultry house. Second, the MQ137 ammonia sensor requires a warm-up period of 24–48 h after the first power-on to achieve stable readings, which could present operational challenges in field deployments involving frequent power cycling. Third, the prototype did not incorporate a local data storage module (e.g., SD card), creating a dependency on continuous Internet connectivity for data persistence. Fourth, the MLX90614 body temperature readings were validated under static conditions and were not assessed for accuracy when the chickens were in motion.

Furthermore, the current prototype was evaluated using a limited number of environmental and operational scenarios. Variations in poultry house design, stocking density, ventilation systems, and seasonal weather conditions were not systematically examined. As a result, the generalizability of the observed performance across different farming environments remains uncertain. Additional field testing under diverse climatic and management conditions is necessary to determine the robustness of the monitoring system and to identify potential calibration requirements for different production settings.

Another limitation relates to the scope of the monitored parameters. Although temperature, humidity, ammonia concentration, and body temperature represent important indicators of poultry welfare, other critical variables such as carbon dioxide levels, feed consumption, water intake, and animal activity patterns were not included in the current implementation. The absence of these complementary indicators may restrict the system's ability to provide a comprehensive assessment of flock health and environmental conditions. Integrating additional sensing modalities in future versions would enable more holistic monitoring and support more informed decision-making for poultry farm management.

4.6 Discussions

The results demonstrate that the proposed Smart Poultry system successfully integrates multiple sensing, communication, and control technologies into a unified IoT-based monitoring platform. The successful resolution of PCB connectivity issues through iterative design refinement highlights the importance of systematic hardware validation during embedded system development. The corrected ESP32-based architecture enabled reliable communication with all sensor modules, while the transition from a dual-layer to a single-layer PCB design significantly reduced fabrication costs without compromising functionality. Furthermore, the stable performance of the DHT22, MLX90614, BMP388, ENS160, and MQ137 sensors confirms the feasibility of combining environmental and physiological monitoring within a single platform. Real-time data transmission to ThingSpeak and successful visualization through the Android application further demonstrate the effectiveness of the end-to-end IoT architecture. These findings support previous studies emphasizing the value of integrated sensor networks for precision livestock farming while extending existing work through the incorporation of non contact body temperature monitoring and multi-parameter environmental sensing.

The actuator control results further confirm the practical applicability of the system for automated poultry house management. The rapid activation of ventilation and heating mechanisms in response to threshold exceedance indicates that the proposed control logic can maintain environmental conditions within acceptable ranges for poultry welfare. Compared with previous IoT-based poultry monitoring systems, the present implementation provides broader sensing capabilities, including ammonia concentration, air quality, atmospheric pressure, and non-contact body temperature measurements, thereby offering a more comprehensive assessment of animal welfare and housing conditions. Nevertheless, the identified limitations, including laboratory-based testing, dependence on continuous internet connectivity, sensor warm-up requirements, and the absence of motion-based body temperature validation, suggest that additional field evaluations are necessary before large-scale deployment. Addressing these limitations would improve system robustness and provide stronger evidence regarding its effectiveness under real-world commercial poultry farming conditions.

5. Conclusions

5.1 Conclusion

In this study, we successfully designed, fabricated, and bench-tested an IoT-based Smart Poultry automation system by integrating five heterogeneous sensor modules (DHT22, MLX90614, BMP388, ENS160, and MQ137) on an ESP32 microcontroller platform. The system achieved its primary objectives: it demonstrated accurate measurement of individual chicken body surface temperatures alongside comprehensive ambient environmental parameter monitoring, and enabled real-time cloud data transmission and remote mobile monitoring.

The PCB design iteration process, necessitated by connectivity errors in the initial schematic and cost constraints in the dual-layer fabrication plan, resulted in a functional and cost-optimized single-layer hardware platform. The successful integration of non-contact infrared thermometry with multi-gas sensing within a unified low-cost IoT system represents the primary novelty of this work, distinguishing the Smart Poultry prototype from the majority of prior systems in the literature.

The automation of environmental control responses, such as temperature-triggered fan and heater activation and ammonia-triggered forced ventilation, demonstrated the system's potential to mitigate heat stress and maintain optimal coop conditions without continuous human intervention. Collectively, these findings support the feasibility of IoT-based precision livestock farming as a viable strategy for improving poultry welfare and production efficiency in tropical agricultural settings.

5.2 Research Limitations

The present study has several important limitations. The experimental environment was a laboratory simulation rather than an operational commercial or smallholder poultry farm, which constrained the ecological validity of the findings. The prototype was evaluated over a relatively short bench-testing period, precluding the assessment of long-term sensor drift, hardware durability, or system reliability across seasonal climate variations. The MQ137 ammonia sensor calibration relied on manufacturer-supplied curves rather than field-specific calibration against a reference instrument, which may have introduced systematic measurement errors. Furthermore, this study did not conduct a formal techno-economic analysis of system deployment costs relative to productivity benefits, which is an essential consideration for adoption by smallholder farmers.

5.3 Suggestions and Directions for Future Research

Based on the findings and limitations of this study, several opportunities for future research can be identified. Future studies should deploy the Smart Poultry prototype in operational commercial and smallholder poultry farms over multiple production cycles to evaluate its real-world effectiveness, sensor durability, and long-term system reliability. In addition, the integration of machine learning techniques, such as anomaly detection and time-series forecasting, could enhance the system’s ability to predict heat stress events before critical thresholds are reached, enabling proactive intervention rather than reactive responses. Another promising direction is the incorporation of RFID or computer vision technologies to link body temperature measurements with individual animals, thereby supporting more precise health monitoring, herd management, and early disease detection.

Further research should also investigate the economic feasibility and scalability of the proposed system. Comprehensive techno-economic analyses comparing implementation costs with productivity improvements, mortality reduction, and operational efficiency gains would provide valuable evidence for broader adoption among poultry farmers. Moreover, transitioning from cloud-dependent architectures to edge-computing frameworks could improve system performance in rural areas where internet connectivity is often limited. Expanding the sensing capabilities of the system through the integration of water consumption monitoring, feed intake sensors, and acoustic stress indicators would provide a more comprehensive assessment of poultry welfare and environmental conditions. Such enhancements would contribute to the development of a more intelligent, adaptive, and sustainable precision livestock farming platform.

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Author Contributions

MFU Conceptualisation, hardware design and fabrication, firmware development, data collection, original draft preparation. AU Supervision, conceptualization, methodology review, manuscript revision, and critical review. A Supervision, PCB design guidance and manuscript review. YY Supervision, project administration, and final approval of manuscript.

References

Aleluia, V. M. T., Soares, V. N. G. J., Caldeira, J. M. L., & Gaspar, P. D. (2023). Livestock monitoring prototype implementation and validation. *Revista de Informática Teórica e Aplicada*, *30*(1), 53-65. https://doi.org/10.22456/2175-2745.127207

Anas, S. A. B., Singh, R. S. S., & Kamarudin, N. A. B. (2022). Designing an IoT agriculture monitoring system for improving farmer’s acceptance of using IoT technology. *Engineering, Technology & Applied Science Research*, *12*(1), 8157-8163. https://doi.org/10.48084/etasr.4667

Aosong Electronics Co. Ltd. (2020). DHT22 (AM2302) digital-output relative humidity and temperature sensor/module datasheet. *Aosong Electronics*.

Astill, J., Dara, R. A., Fraser, E. D. G., Roberts, B., & Sharif, S. (2020). Smart poultry management: Smart sensors, big data, and the internet of things. *Computers and Electronics in Agriculture, 170, 105291*. https://doi.org/10.1016/j.compag.2020.105291

Babiuch, M., Foltýnek, P., & Smutný, P. (2019). Using the ESP32 microcontroller for data processing. *In 2019 20th International Carpathian Control Conference (ICCC) (pp. 1–6). IEEE*. https://doi.org/10.1109/CarpathianCC.2019.8766009

Bosch Sensortec. (2020). BMP388 digital pressure sensor datasheet (Document No. *BST-BMP388-DS001-07, Rev. 1.7). Bosch Sensortec GmbH.*

Choukidar, G. A., & Dawande, N. A. (2017). Smart poultry farm automation and monitoring system. *International Journal of Innovative Research in Science, Engineering and Technology*, *6*(3), 3827-3833..

D’Urso, P. R., Arcidiacono, C., Pastell, M., & Cascone, G. (2023). Assessment of a UWB real-time location system for dairy cows’ monitoring. *Sensors*, *23*(10), 4873. https://doi.org/10.3390/s23104873

Enriko, I. K. A., Rizqiawan, A. P., & Effendi, E. (2021). Automatic temperature control system on smart poultry. *Green Intelligent Systems and Applications*, *1*(1), 37-43. https://doi.org/10.53623/gisa.v1i1.11

Ezema, L. S., Ifediora, E. C., Olukunle, A. A., & Onuekwusi, N. C. (2021). Design and implementation of an ESP32-based smart embedded industrial poultry farm. *European Journal of Engineering and Technology Research*, *6*(3), 103-108. https://doi.org/10.24018/ejeng.2021.6.3.2397

Jain, R., Bhatla, A., Kikani, Y. B., Joshi, D. G., & Patel, K. (2023). Real time cattle health monitoring using IoT, ThingSpeak, and a mobile application. *Journal of Ethology & Animal Science*, *5*(1). https://doi.org/10.23880/jeasc-16000131

Kasakula, W. B., Gatera, O., & Mukanyiligira, D. (2021). *Temperature and humidity control algorithm for poultry farm control systems*.

Kaur, U., Malacco, V. M. R., Bai, H., Price, T. P., Datta, A., Xin, L., Sen, S., Nawrocki, R. A., Chiu, G., Sundaram, S., Min, B.-C., Daniels, K. M., White, R. R., Donkin, S. S., Brito, L. F., & Voyles, R. M. (2023). Invited review: Integration of technologies and systems for precision animal agriculture—A case study on precision dairy farming. *Journal of Animal Science, 101, skad206*. https://doi.org/10.1093/jas/skad206

Khan, M. K., Masood, M., Hussain, M., & Khan, M. A. (2022). *A smart automation system for controlling environmental parameters of poultry farms to increase poultry production*.

Lara, L. J., & Rostagno, M. H. (2023). Impact of heat stress on poultry production: A comprehensive review. *Animals*, *13*(4), 723. https://doi.org/10.3390/ani13040723

Liu, L., Xue, X., Wang, S., & Zhang, J. (2022). Effects of high temperature on poultry production performance: A meta-analysis. *Poultry Science*, *101*(5), 101790. https://doi.org/10.1016/j.psj.2022.101790

Melexis. (2019). MLX90614 family single and dual zone infrared thermometer in TO-39 datasheet (Revision 007). *Melexis Technologies NV*.

Neethirajan, S. (2020). Recent advances in wearable sensors for animal health management. *Sensing and Bio-Sensing Research, 29, 100379*. https://doi.org/10.1016/j.sbsr.2020.100379

Prasanna, K. (2021). PoC design: A methodology for proof-of-concept (PoC) development on Internet of Things connected dynamic environments. *Security and Communication Networks, 2021, Article 7185827*. https://doi.org/10.1155/2021/7185827

Rahayu, S., Kusuma, R. I., & Widyastuti, T. (2020). Analisis akurasi sistem sensor DHT22 berbasis Arduino terhadap thermohygrometer standar. *Jurnal Fisika dan Aplikasinya*, *16*(1), 1-6. https://doi.org/10.12962/j24604682.v16i1.5263

Ren, Y., Duhatschek, D., Bartolomeu, C. C., Erickson, D., & Giordano, J. O. (2023). An automated system for cattle reproductive management under the IoT framework. *Part I: The e-Synch system and cow responses. Frontiers in Animal Science, 4, 1093851*. https://doi.org/10.3389/fanim.2023.1093851

ScioSense. (2020). ENS160 digital metal oxide multi-gas sensor datasheet (Revision 0.95). *ScioSense B.V.*

Shabani, I., Biba, T., & Çiço, B. (2022). Design of a cattle-health-monitoring system using microservices and IoT devices. *Computers*, *11*(5), 79. https://doi.org/10.3390/computers11050079

Shafie, N., Zainab, N. A., Mohd Sam, S., Adam, M. Z., & Azizan, A. (2022). Real-time temperature and humidity monitoring testing approach in poultry farm. *Open International Journal of Informatics*, *10*(2), 24-32. https://doi.org/10.11113/oiji2022.10n2.219

Srithorn, S., Chalermphan, R., & Pruekbuaban, P. (2019). Smart poultry farm based on the real-time environment monitoring. *Naresuan Agriculture Journal*, *16*(2), 18-26..

St-Pierre, N. R., Cobanov, B., & Schnitkey, G. (2023). Economic losses from heat stress by US livestock industries revisited. *Journal of Dairy Science*, *106*(4), 2893-2907..

Walter, A., Finger, R., Huber, R., & Buchmann, N. (2017). Opinion: Smart farming is key to developing sustainable agriculture. Paper presented at Proceedings of the National Academy of Sciences.

Wan, S., Zhao, K., Lu, Z., Li, J., Lu, T., & Wang, H. (2022). A modularized IoT monitoring system with edge-computing for aquaponics. *Sensors*, *22*(23), 9260. https://doi.org/10.3390/s22239260

Winsen Electronics Technology Co. Ltd. (2015). Ammonia gas sensor model MQ137 manual (Version 1.4). *Zhengzhou Winsen Electronics*.

Zaboli, G., Slimen, I. B., Triga, A., & Capozzi, F. (2021). Heat stress in poultry production: Mitigation strategies to overcome the future challenges facing the global poultry industry. *Animals*, *11*(5), 1278. https://doi.org/10.3390/ani11051278