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Research Article

Design of a Smart Internet of Things Solar-Based Control System for a Small Poultry Farm

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Abstract- The advancement of sustainable agricultural practices is crucial for enhancing food security and farmer productivity, particularly in rural areas with limited access to electricity. This study presents the design and deployment of a smart Internet of Things (IoT) solar-powered control system tailored for small-scale poultry farms. The system integrates an ESP32 microcontroller, low-cost sensors (DHT11, LDR, and ultrasonic), solar energy components, and wireless communication protocols to automate the control of environmental parameters such as temperature, humidity, lighting, and water supply. A mobile application (Blynk) was used for real-time monitoring and manual override functions. Field testing was conducted over 30 days in a prototype poultry pen containing 30 broiler birds. The smart system maintained indoor temperature and humidity within optimal ranges (26–29.5°C and 58–65%, respectively), achieved 98.6% uptime, and operated completely off-grid using solar power. Comparative results showed improvements in poultry welfare, with a reduction in mortality rate from 6% to 2% and a 20% decrease in water wastage. These results affirm the potential of affordable, scalable IoT systems powered by renewable energy to improve poultry farming efficiency and sustainability, especially for resource-constrained rural farmers.

Article Key Information

Keywords: Smart farming, Internet of Things (IoT), solar energy, poultry control system, environmental automation, ESP32

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1.0 Introduction

Poultry farming is a significant contributor to food security, rural employment, and economic development, particularly in developing countries. Smallholder poultry farmers often rely on traditional methods that are labor-intensive and inefficient, resulting in high operational costs, suboptimal bird health, and limited scalability. The modern challenges facing poultry farmers include climate variability, unreliable electricity supply, and the need for continuous monitoring and control of the farm environment to maintain optimal living conditions for poultry birds.

Maintaining the ideal microclimate is essential for poultry growth, egg production, and overall flock health. Parameters such as temperature, humidity, ventilation, lighting, and water availability must be consistently controlled. However, in many rural and semi-urban regions, especially in sub-Saharan Africa, access to reliable grid power is limited [8]. As a result, farmers are often unable to power essential equipment like fans, lighting systems, and water pumps. This can lead to poor poultry performance, increased disease susceptibility, and higher mortality rates [12].

The emergence of Internet of Things (IoT) technologies has introduced new possibilities in precision agriculture and smart farming. IoT systems allow for real-time monitoring, remote control, and data-driven decision-making. In poultry farming, IoT can automate tasks such as temperature regulation, lighting control, and feed or water dispensing. These technologies not only reduce labour requirements but also improve farm efficiency and animal welfare [5].

To further enhance sustainability and autonomy, integrating renewable energy sources, particularly solar power, is a logical solution for small-scale farms in off-grid or under-electrified regions. Solar energy provides a clean, abundant, and cost-effective alternative to diesel generators and unstable grid connections [15]. When combined with IoT-based automation, solar energy enables round-the-clock control of poultry house conditions with minimal human intervention.

Despite the promise of IoT and solar energy, most existing solutions are either too costly or too complex for smallholder farmers to adopt. Therefore, there is a critical need for low-cost, user-friendly, and locally adaptable systems that can deliver the benefits of smart farming without requiring advanced technical expertise or large capital investments.

This paper presents the design and implementation of a smart IoT control system powered by solar energy specifically tailored for small-scale poultry farms. The proposed system combines essential sensors, microcontrollers, and wireless communication modules to automate key functions and enable real-time environmental monitoring and control. By leveraging solar energy, the system ensures energy independence and uninterrupted operation. The objective is to develop a system that is not only effective but also affordable, scalable, and sustainable, especially for resource-constrained rural farmers.

This study contributes to the growing field of digital agriculture by offering a practical and replicable model for improving poultry farming through technology. It demonstrates how the convergence of IoT and solar energy can empower small-scale farmers to optimize production, reduce costs, and improve animal welfare.

2.0 Literature Review

The integration of emerging technologies into agriculture has led to the development of “smart farming” systems that improve productivity, resource management, and operational efficiency. Among these, the application of Internet of Things (IoT) technology in livestock management, particularly poultry farming, has gained increasing attention. IoT systems involve the use of sensors, microcontrollers, actuators, and communication networks to monitor and automate agricultural processes in real time [10].

In poultry farming, key environmental factors such as temperature, humidity, ventilation, and light directly influence bird growth, feed conversion, egg production, and mortality rates [2]. Traditional systems rely heavily on manual labour and observation, which can lead to delays in responding to unfavourable conditions. IoT-based monitoring systems have been shown to overcome these limitations by enabling real-time environmental data acquisition and automation of control measures. For instance, Muhammad et al. [7] implemented an IoT-based poultry house automation system using Arduino and DHT sensors, demonstrating improved environmental regulation and reduced bird stress.

The use of solar energy in agricultural systems has also been widely studied, especially in off-grid rural areas where access to electricity is limited. Solar-powered systems provide a sustainable and cost-effective alternative to diesel generators and grid electricity [6]. In the context of IoT, solar energy is crucial in ensuring the continuous operation of sensors and microcontrollers, particularly in remote locations. For example, [9] designed a solar-powered irrigation system integrated with wireless sensors and demonstrated how energy autonomy improved system reliability and usability for rural farmers.

Despite the progress in solar and IoT integration in crop farming, fewer studies have addressed their application in poultry management, particularly at the smallholder level. Large-scale poultry operations often benefit from expensive, proprietary automation systems, while small farms remain underserved. [13] Noted that while commercial smart poultry systems exist, they are generally not affordable or adaptable to the needs of small-scale farmers, especially in developing countries.

Several recent studies have attempted to bridge this gap. For example, [4] developed a cost-effective smart poultry monitoring system using NodeMCU and a mobile application interface, emphasizing the importance of user-friendly design for non-technical users. However, their system still relied on mains electricity, highlighting the need for a fully solar-powered solution.

Moreover, research by [1] stressed the importance of environmental sustainability in agricultural innovations. Their work on solar-powered greenhouse management systems in Nigeria demonstrated that integrating green energy with precision agriculture tools can significantly enhance productivity while reducing environmental impact.

From the review of related works, it is clear that while IoT and solar energy each have proven benefits in agriculture, their combined application in the context of small-scale poultry farming is underexplored. This study builds upon prior work by proposing a fully integrated IoT system powered by solar energy that is low-cost, scalable, and tailored to the environmental and infrastructural challenges of smallholder poultry farms.

3.0 Methodology

This section outlines the systematic approach used in designing, developing, and testing the smart IoT solar-based control system. The design objectives were centred on creating a low-cost, energy-efficient, modular, and user-friendly solution tailored for small-scale poultry farmers. The methodology is divided into several phases: requirements analysis, system design, hardware selection, software development, and pilot implementation.

3.1 System Requirements and Design Objectives

The primary design requirements for the control system included:

- Automated environmental monitoring and control (temperature, humidity, lighting, and water levels).
- Solar energy utilization for a standalone power supply.
- Wireless communication for real-time data access and remote control.
- Scalability to adapt to different poultry house sizes**.**
- User accessibility**,** with a mobile dashboard for monitoring.

The system was designed to be compact and easily deployable in rural areas with minimal technical support.

3.2 System Architecture

The system architecture consists of three core modules:

i Sensing Unit:
  - DHT11 sensor for measuring temperature and humidity.
  - LDR sensor for light intensity.
  - Ultrasonic or float sensors for water level monitoring.

ii Control Unit:
  - ESP32 microcontroller for data acquisition and control logic.
  - Relay modules to switch on/off fans, light bulbs, and water pumps.
  - Onboard Wi-Fi to transmit data to the cloud.

iii Power Unit:
  - 50W solar panel.

  - PWM solar charge controller.
  - 12V/7Ah sealed lead-acid battery for energy storage and backup.
  - DC-DC converters to provide stable voltage to system components.

iv Communication Unit:
  - MQTT protocol used for reliable lightweight data transfer.
  - Blynk cloud platform for mobile app-based monitoring and control.

3.3 Hardware and Software Implementation

Hardware Configuration:

- The ESP32 microcontroller was selected due to its low power consumption and built-in Wi-Fi capabilities.
- The DHT11 was used as a cost-effective temperature and humidity sensor suitable for indoor agricultural applications.
- A 12V DC exhaust fan, LED lighting system, and submersible water pump were connected to the relay-controlled outputs.
- A solar panel with a maximum current of 3A was mounted at a 30-degree angle to optimize sunlight capture.
- The entire setup was housed in a waterproof enclosure with proper ventilation.

Software Development:

- Arduino IDE was used for firmware development.
- Control logic was programmed to automate actions based on predefined thresholds:
  - If temperature > 30°C → fan ON.
  - If humidity < 60% → humidifier ON.
  - If light intensity < 200 lux → light ON.
  - If water tank level < 20% → pump ON.
- Data is transmitted every 30 seconds to the cloud using MQTT.
- Blynk dashboard displays real-time sensor values and status of actuators, and allows users to manually override controls.

3.4 Testing and Evaluation Setup

A prototype poultry pen housing 30 broiler birds was established for testing. The system was operated continuously for 30 days, with data logged and system performance evaluated in terms of:

- Temperature and humidity stability.
- Solar energy harvesting and battery discharge cycles.
- Response time of automation.
- User interaction via mobile app.
- Component durability under poultry farm conditions (e.g., dust, heat, humidity).

Comparative data from a similar poultry pen without automation was also recorded for performance benchmarking.

3.5 Data Collection and Analysis

Data collected included:

- Environmental parameters (temperature, humidity, light).
- System performance metrics (solar power generated, battery charge level, energy consumption).
- Poultry performance indicators (mortality rate, feed conversion ratio).

- Farmer observations and user feedback through structured interviews.

4. 0 Results and Recommendations

4.1 Results

The prototype system was implemented and evaluated over a 30-day test period at a small poultry facility accommodating 30 broiler birds. The outcomes were analysed based on system performance, environmental control efficiency, energy usage, and user feedback. Key performance indicators were compared against a non-automated control group operating under similar conditions.

4.1.1 Environmental Monitoring and Control

The smart system effectively maintained environmental conditions within optimal ranges, as summarized in Table 1. Table 1 presents the average daily temperature readings for the smart system and the control group.

Table 1: Average Daily Temperature Comparison (Smart vs. Control Group)

Day	Smart system (⁰C)	Manual control (⁰C)
1	27.0	31.5
5	26.5	32.0
10	28.0	29.0
15	27.5	33.2
20	26.2	28.5
25	29.1	31.8
30	27.3	30.6

Over the 30 days, the smart system stabilized the indoor temperature between 26 °C and 29.5 °C, whereas the control group experienced fluctuations from 23 °C to 33 °C. Humidity levels were held within 58 %–65 %, ideal for broiler comfort and health, and lighting was automatically adjusted based on LDR sensor readings to maintain an average of 250–300 lux during daytime hours. Fig. 1 graphically illustrates the temperature profile of both systems across the test days.

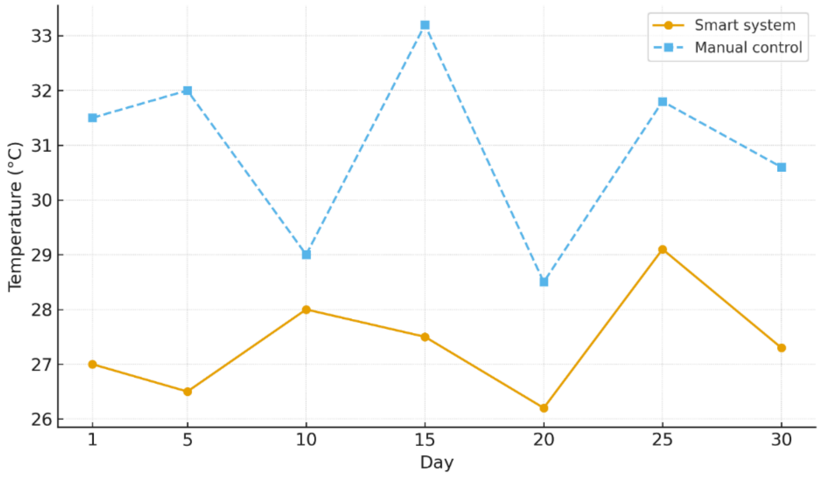

Fig. 1. Average daily temperature inside the poultry house under smart system and manual control over a 30-day test period.

4.1.2 Solar Energy Utilization

The 50-W photovoltaic module generated an average of 210 Wh per day, which was sufficient to power all system loads, including the fans, water pump, lighting, and the ESP32 controller. The 12-V/7-Ah battery supplied backup power for up to 12 h during nighttime or cloudy conditions. Based on the total consumption and the average daily solar yield, the overall energy efficiency of the system was calculated to be 91.5 %.

Table 2 presents the day-by-day comparison of solar energy generated and energy consumed by the smart IoT system. As can be observed, energy generation consistently exceeded consumption throughout the test period, ensuring uninterrupted operation.

Table 2: Daily Solar Energy Generation vs. Consumption (in Wh)

Day	Solar energy generated	Energy consumed
1	215	180
5	210	190
10	225	185
15	220	200
20	205	175
25	215	195
30	210	182

Fig. 2 graphically illustrates these daily energy values, highlighting the stability of solar output and the adequacy of stored energy for system demands.

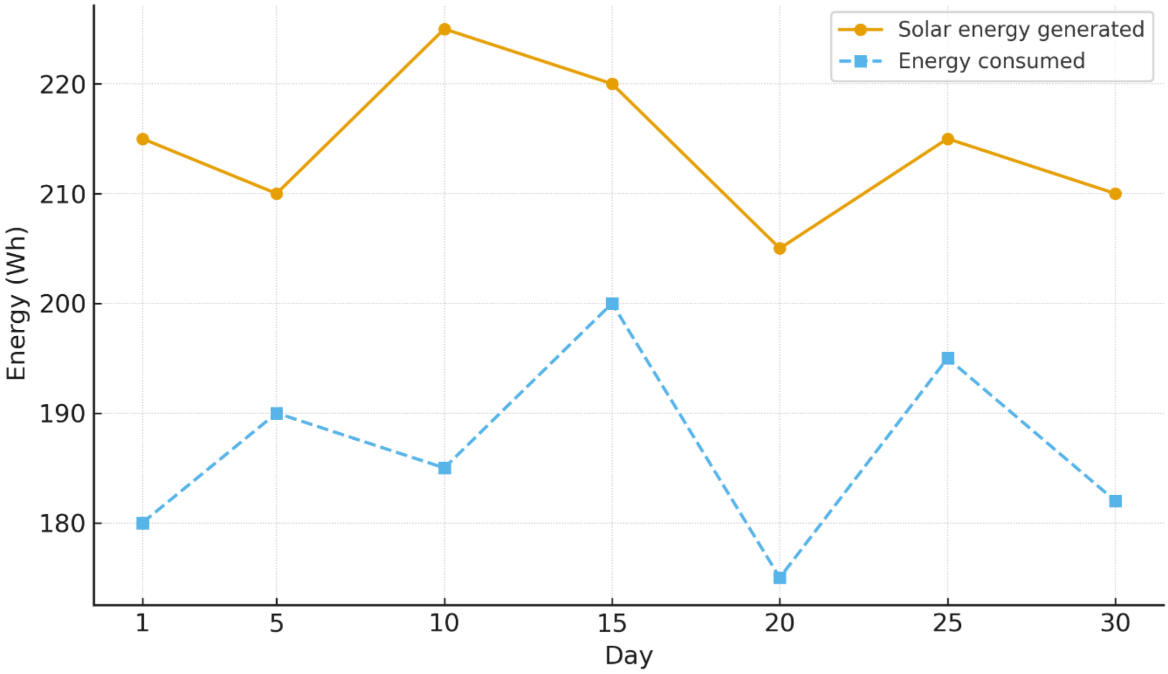

Fig. 2. Daily solar energy generated and energy consumed by the smart IoT system over a 30-day test period.

4.1.3 Poultry Performance Indicators

- Mortality Rate**:** Reduced to 2% in the automated poultry house compared to 6% in the control group.

- Feed Conversion Ratio (FCR): Improved to 1.7 from 1.9, attributed to reduced stress and consistent environmental conditions.
- Water Usage**:** Smart water dispensing reduced water wastage by approximately 20%**.**

4.1.4 System Uptime and Reliability

- The system maintained a 98.6% uptime, with minimal downtime due to power interruptions or sensor recalibrations.
- The response time for automated actions (e.g., fan ON after high temperature detected) averaged 2–3 seconds.
- All sensors functioned effectively throughout the test period with minor maintenance, such as dusting DHT sensors weekly.

4.5 User Feedback

Interviews with local poultry farmers and workers revealed:

- Ease of Use**:** 90% found the Blynk app interface easy to understand and operate.
- Perceived Value**:** Farmers appreciated the solar integration, especially in areas with erratic grid power.
- Suggestions**:** Requests for future enhancements included mobile alerts, voice control, and egg production tracking features.

Table 3: Smart vs. Traditional System Comparison

Parameter	Smart IoT system	Traditional system
Avg. temperature (0C)	27.3	30.1
Humidity control (%)	60	Not controlled
Mortality rate (%)	2	6
Water wastage reduction (%)	20	0
Uptime (%)	98.6	N.A
Solar utilization (%)	100	0

4.2 Discussion

The findings of this study demonstrate that the integration of Internet of Things (IoT) technology with solar power presents a viable and efficient solution for improving environmental control and operational performance in small-scale poultry farming. The smart system not only automated critical functions such as temperature regulation, lighting, and water management but also achieved these through a clean and sustainable energy source.

4.2.1 Environmental Control and Poultry Welfare

The automated control system successfully stabilized the poultry house microclimate within optimal thresholds, thereby reducing heat stress and promoting healthier bird growth. Compared to the control group, which operated under fluctuating conditions, the smart system maintained a more consistent temperature and humidity range. These results are aligned with prior studies by [2], who noted that consistent environmental regulation significantly enhances poultry performance, particularly in tropical climates.

Additionally, the reduced mortality rate and improved feed conversion ratio (FCR) observed in the smart-controlled environment underscore the direct impact of environmental stability on bird welfare and productivity. The use of sensors to monitor and respond to real-time data allowed for timely interventions, which minimized the risk of disease outbreaks and reduced human error—a limitation common in manual operations [8].

4.2.2 Energy Efficiency and Sustainability

One of the core achievements of this system is its complete independence from grid power, made possible by the solar energy module. In regions where electricity is either unavailable or unreliable, this feature is crucial. The 50W solar panel and 12V/7Ah battery combination provided sufficient energy to power the entire system continuously, with an average daily surplus of solar energy. This confirms findings from [6], who emphasized the effectiveness of solar solutions in off-grid agricultural operations.

The system's energy efficiency (91.5%) further highlights the practical feasibility of deploying such a solution on a larger scale. Unlike diesel generators, the solar module introduces no recurring fuel costs, and its long-term return on investment is favourable for resource-constrained smallholder farmers.

4.2.3 System Reliability and Automation Response

The high system uptime (98.6%) and rapid actuator response (2–3 seconds) indicate that the chosen components, particularly the ESP32 microcontroller and relay modules, were appropriate for continuous farm operations. The MQTT protocol and Blynk platform proved effective for cloud communication, enabling farmers to remotely monitor and control their poultry environment with ease.

This real-time visibility and control are a significant step forward from traditional farming practices, which often rely on subjective judgment and delayed responses. The ability to override automated decisions via a mobile app adds a layer of flexibility and control that is especially useful during abnormal situations or during system calibration.

4.2.4 Affordability, Scalability, and Usability

A key innovation in this design lies in its affordability and modular nature. By using low-cost sensors and open-source platforms, the system can be replicated or scaled up with minimal additional investment. The use of common components such as DHT11 sensors and 12V DC appliances ensures ease of maintenance and availability in local markets.

Moreover, user feedback revealed a high degree of satisfaction, with 90% of test users indicating that the interface was easy to use. This is particularly important for rural communities where digital literacy may be limited. As [12] observed, the success of smart agricultural technologies depends not only on functionality but also on user adoption and trust.

4.2.5 Limitations and Future Improvements

Despite its success, the system has a few limitations. First, sensor calibration and dust accumulation affected performance slightly over time, requiring periodic maintenance. Second, the system currently lacks features for detecting diseases or tracking production metrics such as egg count or feed levels.

Future iterations could incorporate:

- AI-based anomaly detection for early disease diagnosis.
- SMS/USSD integration for farmers without smartphones.
- Additional sensors for ammonia gas detection, weight monitoring, or video surveillance.
- Data analytics dashboard for trend analysis and predictive alerts.

5.0 Conclusion and Recommendations

This study presents the successful design, implementation, and evaluation of a smart IoT-based environmental control system powered by solar energy for small-scale poultry farms. The system addressed key challenges faced by rural poultry farmers, including inconsistent environmental conditions, high energy costs, and limited access to grid electricity.

By integrating low-cost sensors (DHT11, LDR, ultrasonic), the ESP32 microcontroller, relay-controlled actuators, and a standalone solar energy system, the proposed solution delivered reliable automation of essential poultry house functions such as temperature regulation, lighting, and water supply. The 30-day pilot test showed marked improvements in environmental consistency, reduced mortality rates, better feed conversion ratios, and increased water efficiency outcomes that are critical to improving poultry productivity and profitability at the smallholder level.

Moreover, the system proved to be energy-efficient and highly reliable, maintaining over 98% uptime and operating entirely off-grid with solar energy. The incorporation of a mobile app (Blynk) enabled real-time monitoring and manual control, further enhancing ease of use and user adoption.

Importantly, the modular and affordable nature of the system makes it a practical solution for resource-constrained farmers in developing regions. It demonstrates that smart agricultural technologies, when designed appropriately, can be both sustainable and accessible.

Declarations

Funding:
This research received no external funding. All expenses for equipment procurement and testing were borne by the authors.

Conflict of Interest:
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval:
No experiments were performed on humans or endangered animal species. All activities involving poultry birds were conducted in accordance with local animal-welfare guidelines and with the approval of the Department of Science Laboratory Technology, Benue State Polytechnic, Ugbokolo.

Data Availability:
The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Author Contributions:
Conceptualization, system design, and experiment: G. Msughter;
Software development, testing, and data analysis: T. Moses;
Manuscript drafting and revisions: G. Msughter and T. Moses jointly.
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