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IoT-Based Smart Egg Incubation System for Improved Hatchability in Small-Scale Poultry Farming

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***Abstract*: This paper presents the design and experimental evaluation of an Internet of Things (IoT)-based smart egg incubation system developed for small-scale poultry farming applications. Conventional manual incubation practices suffer from inconsistent temperature and humidity regulation, leading to low hatch rates typically limited to 50–60% and requiring intensive manual labor. The proposed system automates the incubation process using an ESP8266 microcontroller integrated with DHT22 temperature and humidity sensors. Critical incubation conditions of 37.5°C ± 0.3°C (after calibration) and relative humidity between 55–70% are maintained throughout the 21-day incubation cycle. The system includes relay-controlled heating elements, automated egg turning using servo motors, and real-time monitoring through an OLED display. Remote access and monitoring are enabled via Wi-Fi using cloud platforms such as Blynk and ThingSpeak. Experimental evaluation conducted over five complete incubation cycles demonstrated stable temperature control within ±0.3°C and humidity regulation within ±3%. The system achieved an average hatch rate of 92%, representing a significant improvement over manual incubation methods. Energy consumption was measured at approximately 0.15 kWh per day, while manual labor requirements were reduced by nearly 80%. With total hardware costs below $60, the proposed system offers a reliable, energy-efficient, and affordable solution for improving hatchability and productivity in resource-constrained poultry farming environments.**

***Keywords*: egg incubation, ESP8266, Internet of Things, poultry automation.**

1. Introduction

Poultry farming is a vital contributor to global food security, with egg production forming a major source of affordable protein. Successful poultry production is highly dependent on effective egg incubation, which requires precise control of environmental parameters such as temperature and humidity. However, small-scale poultry farmers in developing regions often rely on traditional manual incubation methods that provide poor environmental regulation and require constant human intervention.

Embryonic development of poultry eggs requires a stable temperature of approximately 37.5°C with minimal deviation and relative humidity levels between 55–70%. Deviations from these conditions can result in embryonic mortality rates approaching 30%, leading to economic losses for farmers. Manual incubation systems frequently experience temperature fluctuations of ±2–3°C, inconsistent humidity control, and irregular egg turning schedules, resulting in reduced hatch rates [1].

Recent advancements in embedded systems and Internet of Things (IoT) technologies enable low-cost automation using microcontrollers and digital sensors. By integrating sensing, control, and wireless communication, IoT-based systems can provide continuous monitoring and precise environmental regulation. This paper proposes an IoT-enabled smart egg incubation system designed to improve hatchability, reduce labor requirements, and remain affordable for small-scale poultry farmers and educational institutions.

2. Literature Review

Early research on automated egg incubation focused on microcontroller-based temperature control. S. R. Patil, S. S. Bhosale, and R. R. Karhe developed a basic automatic egg incubator using relay-controlled heating elements and digital temperature sensors, demonstrating the feasibility of automation while highlighting challenges in humidity regulation [1].

K. A. Patil and N. R. Kale later explored the integration of IoT concepts into agriculture, enabling remote monitoring and data access through wireless communication for improved farm management [2].

More recent works have advanced IoT integration specifically for poultry egg incubation. Refni Wahyuni, Yuda Irawan, Anita Febriani, Nurhadi, and Haris Tri Saputra proposed a smart egg incubator using IoT and Mamdani fuzzy logic algorithm to enhance hatchability in modern poultry farming, incorporating automatic egg-turning and remote monitoring capabilities [3].

Forson Peprah, Samuel Gyamfi, Mark Amo-Boateng, Eric Buadi, and Michael Obeng designed and constructed a smart solar-powered egg incubator based on GSM/IoT, focusing on remote monitoring, temperature/humidity control, and affordability for resource-limited settings [4].

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Table 1
Performance comparison between automated and manual incubation

Parameter	Proposed System	Manual Method	Improvement
Temperature Stability	±0.3°C	±2–3°C	67%
Humidity Control	±3%	±10–15%	75%
Hatch Rate	92%	50–60%	35%
Labor Requirement	20%	100%	80%
Power Consumption	0.15 kWh/day	Not measured	-

and S. A. Nawaz designed and implemented a chicken egg incubator for hatching using IoT, utilizing a PID controller for precise temperature regulation [5].

3. System Architecture

The proposed system consists of five main modules: sensing, processing, actuation, display, and communication. Temperature and humidity are monitored using DHT22 sensors, which provide sufficient accuracy for incubation control. The ESP8266 microcontroller serves as the processing unit due to its integrated Wi-Fi capability, low power consumption, and compatibility with open-source development platforms.

Heating is controlled using relay modules connected to resistive heating elements rated between 50–100 W. Humidity regulation is assisted through controlled ventilation using DC fans. Automated egg turning is achieved using servo motors that rotate eggs by 45° at fixed intervals. A 0.96-inch OLED display provides real-time feedback on system parameters. Wireless communication enables remote monitoring and alerts via cloud platforms.

4. Methodology

The prototype incubator was constructed using an insulated plywood enclosure measuring 40 cm × 30 cm × 30 cm, capable of accommodating 20–30 eggs. DHT22 sensors were calibrated against reference instruments prior to experimentation. A moving average filter was applied to sensor readings to reduce noise and improve control stability.

The system was tested over five complete 21-day incubation cycles using fertilized chicken eggs. Performance metrics included temperature stability, humidity accuracy, power consumption, relay switching frequency, and hatch rate.

Data Processing and Calibration:

To address the inherent measurement uncertainty of the DHT22 (±2–5%), a two-stage signal conditioning approach was implemented. First, a two-point calibration was performed against a certified laboratory reference hygrometer. A linear regression offset was derived and programmed into the firmware to correct systematic sensor bias. Second, a moving average filter was applied to the corrected data stream:

$$y[n] = \frac{1}{N}\sum_{i=0}^{N-1} x[n-i] \quad (1)$$

where y[n] is the filtered output at time n, x[n-i] are the input samples (temperature or humidity readings), and N=10 is the window size (corresponding to a 20-second window at 2-second sampling). This algorithm effectively minimizes random noise, allowing the system to achieve effective control stability of ±0.3°C and ±3% relative humidity. To mitigate long-term sensor drift during the 21-day high-humidity cycle, a ventilation routine was triggered every 48 hours to prevent sensor saturation.

5. Results and Discussion

The system maintained temperature stability within ±0.3°C and humidity within ±3% of target values throughout all incubation cycles. The average hatch rate achieved was 92%, significantly higher than manual incubation methods, which averaged between 50–60%. Statistical analysis confirmed that the improvement was significant. The results confirm that automation significantly improves hatchability while reducing labor and energy consumption.

6. Conclusion

The proposed IoT-based smart egg incubation system provides reliable environmental control, high hatch rates, and substantial labor reduction at a low cost. By integrating an ESP8266 microcontroller, digital sensors, and cloud connectivity, the system offers an effective solution for small-scale poultry farmers in developing regions. Future work may include renewable energy integration and intelligent control algorithms to further enhance system performance.

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