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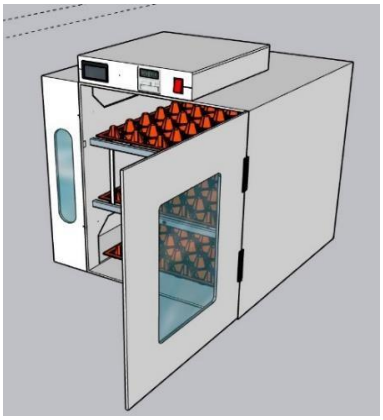
Full Paper

Iot-Based Smart Egg Incubator With Real-Time Temperature And Humidity Monitoring And Control Using The Mqtt Protocol

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Graphical Abstract



Abstract
The chicken egg hatching process relies heavily on stable temperature and humidity levels within the incubator. Poorly monitored conditions can reduce hatching success rates. Therefore, a smart incubator capable of automatically monitoring and controlling environmental conditions in real-time is required. This study aims to design an Internet of Things (IoT)-based Smart Egg Incubator using an ESP32 microcontroller and MQTT communication. A DHT22 sensor is used to measure temperature and humidity, with data transmitted to a monitoring system for remote device control. The system integrates a relay, heating lamp, circulation fan, mist maker, egg tray motor, and an OLED screen for local display. Test results indicate that the sensor provides stable temperature and humidity readings. Data transmission is fast and consistent. The control system successfully maintains the temperature required for incubation, and humidity levels are kept within the desired range. Actuators respond effectively to commands. Real-time condition monitoring proceeds without significant interruption, and the system operates continuously throughout testing. Hardware and IoT integration functions effectively. It is concluded that the Smart Egg Incubator successfully maintains stable incubation conditions. The system is effective for remote monitoring and control, offering the potential to improve egg hatching success rates.

Keywords: Internet of Things, Smart Egg Incubator, ESP32, DHT22, MQTT.

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1. INTRODUCTION

The poultry industry continues to grow due to the increasing demand for animal protein, making artificial egg incubation an important technology to improve hatchability. Successful incubation depends primarily on maintaining stable temperature and humidity throughout the incubation period. Chicken eggs require an incubation temperature of approximately 37–38°C and relative humidity of 55–60% during the early incubation stage. Any significant deviation from these conditions may inhibit embryo development and reduce hatching success. Conventional incubators generally require manual monitoring and adjustment, resulting in unstable environmental conditions and increasing the possibility of incubation failure [1]-[6].

The development of the Internet of Things (IoT) has enabled remote monitoring and automatic control of environmental parameters in agricultural applications. By integrating sensors, microcontrollers, and wireless communication, IoT allows users to monitor incubator conditions in real time using smartphones or computerswithout directly opening the incubator. This capability improves operational efficiency while

minimizing disturbances to the incubation environment. Several previous studies have developed IoT-based egg incubators using Arduino, ESP8266, ESP32, and various IoT platforms. These systems successfully implemented automatic monitoring and control of temperature and humidity. However, several limitations remain, including unstable communication, dependence on internet connectivity, limited monitoring features, absence of automatic notification, and insufficient environmental control accuracy. Some studies also reported that conventional incubators still experience unstable temperature regulation, manual humidity adjustment, and low hatching performance due to delayed monitoring [7]-[8].

The contribution of this study is not claimed from the use of ESP32 and MQTT alone, since both technologies have been widely applied in IoT-based monitoring systems. Instead, this study focuses on the practical integration of threshold-based environmental control, MQTT-based remote monitoring, and scheduled egg turning in a compact Smart Egg Incubator prototype. The ESP32 processes temperature and humidity measurements from the DHT22 sensor and determines the operating conditions of the heater, fan, and mist maker based on predefined thresholds. Meanwhile, MQTT is used to transmit sensor measurements and actuator-status information to the remote monitoring application. The proposed system is evaluated through sensor measurement error, actuator response, MQTT communication, and scheduled egg-turning operation. [9]-[13].

2. METHOD

2.1 System Architecture

The proposed Smart Egg Incubator is designed as an IoT-based monitoring and control system. The main controller is an ESP32, which receives temperature and relative humidity measurements from a DHT22 sensor. Based on the measured conditions, the ESP32 controls the heater, fan, and mist maker through a relay module. An automatic motor mechanism is also used to turn the egg rack according to a predefined schedule.

For local monitoring, an OLED display is connected directly to the ESP32 to display the current system conditions. For remote monitoring, the ESP32 communicates with an MQTT broker through a Wi-Fi network. The MQTT broker distributes the published data to the Kodular-based monitoring application [3], [14].

The overall system architecture consists of the following data and control paths:

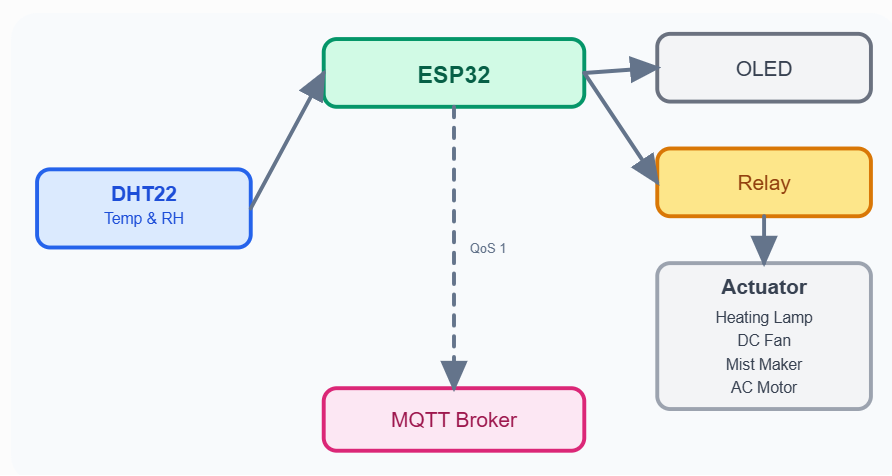


Figure 1. Proposed Smart Egg Incubator system architecture

2.2 Hardware and Software Components

The main hardware components consist of an ESP32 microcontroller, DHT22 temperature and humidity sensor, relay module, heating lamp, DC fan, ultrasonic mist maker, motor for the egg-turning mechanism, and OLED display. The ESP32 functions as the central controller that processes sensor measurements and controls the actuators.

The software system consists of the ESP32 control program, MQTT communication, and a Kodular-based remote monitoring application. MQTT is implemented using a publish-subscribe communication model. The ESP32 acts as an MQTT client and publishes sensor measurements and actuator-status information to dedicated topics under the capstone/device1/ topic hierarchy. The programmed publication interval is 3 seconds, and QoS level 1 is used for MQTT communication. The system also implements a reconnection mechanism when the Wi-Fi or MQTT connection is interrupted [15]-[19].



Figure 2 — Prototipe Smart Egg Incubator

2.3 Temperature and Humidity Control

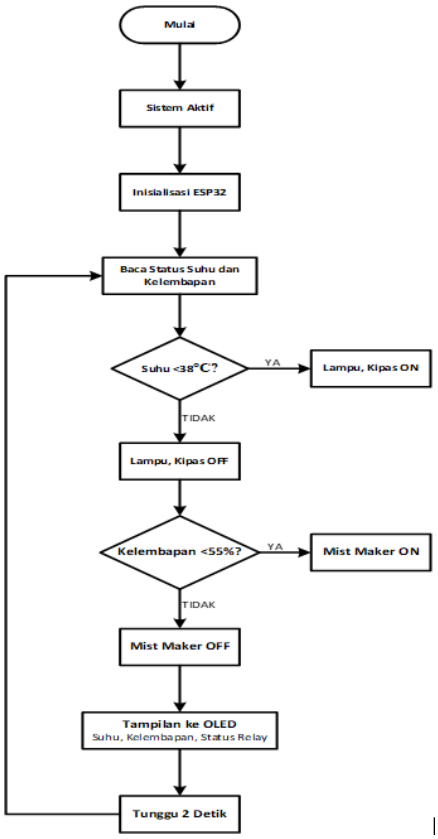


Figure 3. Flowchart of the proposed monitoring and control system

The environmental control process is implemented directly on the ESP32 using threshold-based ON/OFF logic. The DHT22 measures temperature and relative humidity, and the ESP32 evaluates the measurements at a programmed interval of 3 seconds.

For incubation days up to day 18, the temperature threshold used by the program is 37.8–38.0°C, while the humidity threshold is 55–60%. When the temperature is below 37.8°C, the heater and fan are activated. When the temperature exceeds 38.0°C, the heater and fan are deactivated. When the temperature is within the 37.8–38.0°C range and humidity exceeds 60%, the heater and fan are activated. The mist maker is activated when humidity is below 55% and deactivated when humidity reaches or exceeds 55% [20].

For incubation days above day 18, the humidity range is changed by the program to 65–75%, while the temperature range remains 37.8–38.0°C. The control conditions are summarized in Table 1.

Table 1. Threshold-based temperature and humidity control conditions

Condition	Temperature	Humidity	Heater & Fan	Mist Maker
Cold	<37.8°C	Any	ON	Based on RH
Ideal	37.8–38.0°C	<55%	OFF	ON
Ideal	37.8–38.0°C	55–60%	OFF	OFF
Ideal	37.8–38.0°C	>60%	ON	OFF
Hot	>38.0°C	Any	OFF	Based on RH

Note: For incubation days above day 18, the humidity reference range is changed to 65–75% by the control program.

2.4 Egg-Turning Mechanism

The egg-turning mechanism is driven by an AC motor controlled through a relay module. The ESP32 uses the millis() timer to activate the relay every 6 hours, allowing the AC motor to rotate the egg rack for 5 seconds before stopping automatically.

The movement sequence consists of Center–Left, Left–Center, Center–Right, and Right–Center, and repeats cyclically without manual intervention.

2.5 MQTT Remote Monitoring

The ESP32 publishes temperature, humidity, actuator status, and egg-turning information to the MQTT broker. Each parameter is transmitted using a dedicated topic to allow the Kodular application to receive and display the corresponding information.

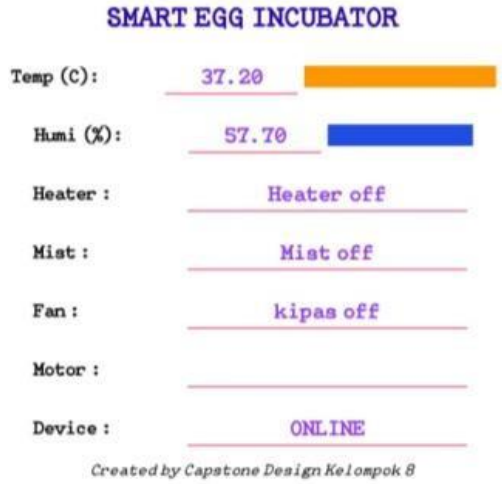


Figure 4. Remote monitoring interface developed using Kodular

The MQTT communication uses QoS level 1, which provides acknowledgment-based message delivery with at-least-once delivery semantics. Selected messages can be configured as retained messages so that the latest status remains available when a new subscriber connects. The payload contains numerical sensor values or textual actuator-status information. When the connection is interrupted, the ESP32 attempts to reconnect to the Wi-Fi network and MQTT broker.

3. RESULTS AND DISCUSSION

3.1 DHT22 Sensor Test

The DHT22 sensor was evaluated at five representative incubation stages (Days 1, 7, 14, 18, and 21). Temperature and humidity measurements were compared with reference instruments to determine sensor accuracy. The programmed temperature range was 37.8–38.0°C, while the humidity reference was maintained at 55–60% during the early incubation stage. Small fluctuations in the measured values occurred because the heater, fan, and mist maker were controlled using hysteresis-based ON/OFF logic.

The temperature measurement error ranged from 1.03% to 1.12%, while the humidity measurement error ranged from 1.11% to 1.20%. These results indicate relatively small differences between the DHT22 measurements and the reference measurements at the evaluated incubation stages. The measurements represent selected test stages rather than continuous 24-hour time-series data. Therefore, the results demonstrate the measurement accuracy of the DHT22 sensor at the tested incubation stages but do not quantitatively establish long-term environmental stability.

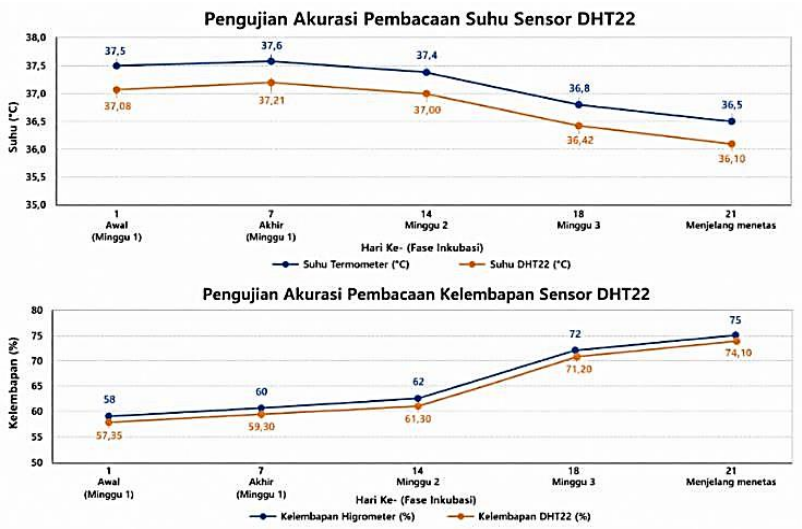


Figure 5. Comparison of DHT22 and reference temperature measurements

3.2 Actuator Response Test

The actuator test was conducted to verify the response of the heater, fan, and mist maker to the environmental conditions measured by the DHT22. The ESP32 processes the sensor values and compares them with the programmed threshold values.

When the measured temperature falls below 37.8°C, the heater and fan are activated. When the temperature exceeds 38.0°C, both devices are deactivated. The mist maker responds to the humidity condition and is activated when the humidity is below the specified lower threshold.

The test confirms that the actuators respond according to the threshold-based control algorithm implemented in the ESP32. This demonstrates the functional relationship between sensor measurement, decision-making, and actuator operation.

3.3 MQTT Communication Test

The MQTT communication test confirmed that temperature, humidity, actuator status, and egg-turning information could be transmitted from the ESP32 to the remote monitoring application.

The programmed publication interval for sensor and actuator information is 3 seconds, and QoS level 1 is used for MQTT communication. The system also provides a reconnection mechanism when the Wi-Fi or MQTT connection is interrupted.

The 3-second interval represents the programmed publication interval and should not be interpreted as an end-to-end MQTT latency measurement. Therefore, the test confirms data transmission functionality but does not quantify the actual communication latency between the ESP32 and the Kodular application.

3.4 Egg-Turning Test

The egg-turning mechanism was tested to verify the scheduled operation of the motor. The motor is programmed to operate automatically every 6 hours for 5 seconds.

The motor follows the programmed movement sequence consisting of Center-to-Left, Left-to-Center, Center-to-Right, and Right-to-Center. The sequence is repeated cyclically according to the scheduled operation.

The test demonstrates that the egg-turning mechanism can operate automatically without manual activation during normal system operation.

3.5 Discussion

The experimental results demonstrate that the proposed Smart Egg Incubator successfully integrates environmental sensing, threshold-based actuator control, MQTT communication, and automatic egg turning within a single ESP32 platform. The DHT22 achieved temperature errors of 1.03–1.12% and humidity errors of 1.11–1.20%, indicating satisfactory measurement performance during the selected incubation stages.

Compared with previous IoT-based incubator studies, this prototype provides comparable measurement accuracy while additionally implementing QoS level 1 MQTT communication and a scheduled egg-turning mechanism operating every 6 hours for 5 seconds. Unlike systems that only perform remote monitoring, the ESP32 in this study also executes local decision-making using hysteresis-based threshold control, allowing the heater, fan, and mist maker to respond automatically to environmental changes.

Compared with previous IoT-based egg incubator systems, the proposed prototype achieved comparable temperature measurement accuracy (1.03–1.12%) while additionally implementing QoS Level 1 MQTT communication and an automatic egg-turning mechanism operating every 6 hours. These features improve the reliability of remote monitoring and autonomous incubation control

Table 2. Comparison of the proposed Smart Egg Incubator with previous IoT-based incubator system

Parameter	Previous IoT Incubator	This Study
Controller	ESP32	ESP32
MQTT	Yes	QoS Level 1
Temperature Error	1.3–1.5%	1.03–1.12%
Egg Turning	Automatic	Every 6 h
Local OLED	Limited	Yes
Remote Monitoring	Yes	Kodular + MQTT

4. CONCLUSION

The Smart Egg Incubator prototype successfully integrates DHT22-based environmental monitoring, threshold-based actuator control, MQTT remote monitoring, and automatic egg turning using an ESP32. The DHT22 evaluation showed temperature measurement errors of 1.03–1.12% and humidity measurement errors of 1.11–1.20% at the selected incubation stages. The environmental control system uses a temperature range of 37.8–38.0°C, while the humidity reference is adjusted according to the incubation stage. MQTT communication uses QoS level 1 with a programmed publication interval of 3 seconds for monitoring data. The egg-turning mechanism operates automatically every 6 hours for 5 seconds using a time-based control algorithm. Overall, the results demonstrate the functional operation and integration of the proposed monitoring, control, communication, and egg-turning subsystems. However, continuous environmental stability, end-to-end MQTT latency, energy consumption, and quantitative hatchability performance were not evaluated. These aspects should be addressed in future research to provide a more comprehensive evaluation of the Smart Egg Incubator.

REFERENCES

[1] Y. A. Yunus, R. Satra, and F. Fattah, "Sistem Monitoring Suhu pada Inkubator Penetas Telur Berbasis IoT," Literatur Informatika & Komputer, vol. 1, no. 4, pp. 389–394, 2024, doi: 10.33096/linier.v1i4.2538.

[2] U. Wira Yuda and T. Sutabri, "Pengembangan Inkubator Telur Ayam Berbasis IoT dan Arduino dengan Metode Prototipe Sistem Kontrol Suhu," Jurnal Sains Student Research, vol. 3, no. 2, pp. 401–409, Apr. 2025, doi: 10.61722/jssr.v3i2.4321.

[3] A. Pawar, M. Patki, O. Shirse, and V. S. Jadhav, "IoT-Based Smart Egg Incubation System for Improved Hatchability in Small-Scale Poultry Farming," International Journal of Research in Engineering, Science and Management, vol. 9, no. 1, pp. 30–32, Jan. 2026

[4] M. Zirana and R. Meisarah, Prototype Alat Penetas Telur Berbasis IoT. Sungailiat: Politeknik Manufaktur Negeri Bangka Belitung, 2023.

[5] Yanti, A. Rohman, S. Maesaroh, A. Mustopa, and R. M. Febrian, "The Implementation of the Internet of Things in the Duck Egg Incubator Monitoring System," TIERS Information Technology Journal, vol. 3, no. 2, pp. 84–90, Dec. 2022, doi: 10.38043/tiers.v3i2.3891.

[6] F. A. Maharani, F. Magfirah, H. Nirwana, and F. Ulfiah, "Rancang Bangun Alat Penetas Telur Otomatis Berbasis IoT," in Prosiding Seminar Nasional Teknik Elektro dan Informatika (SNTEI), Makassar, Indonesia, Sep. 2021, pp. 245–250.

[7] M. Anang Sucipto and S. B. Prakoso, "Rancang Bangun Alat Penetas Telur Otomatis Berbasis Arduino," Jurnal FORTECH, vol. 3, no. 1, pp. 43–50, 2022, doi: 10.56795/fortech.v3i1.106.

[8] M. R. R. Jusman, S. Masita, I. Isminarti, and M. Dzarfaraby, "Sistem Kontrol & Monitoring Mesin Penetas Telur Berbasis IoT (Internet of Things)," MAPLE, vol. 3, no. 2, 2021.

[9] A. N. Maroma, D. P. Maroma, and B. A. Pangilinan, "Development of Automated Egg Incubator With Backup Power Supply," ASEAN Journal of Community Engagement, vol. 7, no. 2, pp. 151–164, Dec. 2023, doi: 10.7454/ajce.v7i2.1222.

[10] K. B. Azahar, E. E. Sekudan, and A. M. Azhar, "Intelligent Egg Incubator," International Journal of Recent Technology and Applied Science, vol. 2, no. 2, pp. 91–102, 2020, doi: 10.36079/lamintang.ijortas-0202.129.
[11] R. Wahyuni, Y. Irawan, A. Febriani, N. Nurhadi, H. T. Saputra, and R. Andrianto, "Smart Egg Incubator Based on IoT and AI Technology for Modern Poultry Farming," ILKOM Jurnal Ilmiah, vol. 16, no. 2, pp. 134–144, Aug. 2024, doi: 10.33096/ilkom.v16i2.1957.134-144.
[12] D. Zakaria, M. B. Hamzah, D. S. Nazhif, M. H. Muttaqin, M. R. Wahid, R. B. Prayudha, A. Ramelan, and A. Nugraha, "Egg Incubator Control System: A Review," Journal of Electrical, Electronic, Information, and Communication Technology, vol. 5, no. 1, pp. 33–37, Apr. 2023, doi: 10.20961/jeeict.5.1.72718.
[13] I. S. H. Kocher and G. Y. Izadeen, "Smart Egg Incubator Based on Microcontroller: A Review," Academic Journal of Nawroz University, vol. 11, no. 4, pp. 139–147, Nov. 2022, doi: 10.25007/ajnu.v11n4a1401.
[14] E. Supriyadi, F. Marwita, I. Ilyas, and W. Dwicaksana, "Control and Monitoring System of Egg Hatching in Egg Hatching Incubator Based on Internet of Things (IoT)," International Journal of Accounting & Management (IJAM), vol. 4, no. 2, pp. 320–332, 2025.
[15] R. A. Tarigan, A. Fauzi, and M. A. Syari, "Rancang Bangun Inkubator Penetasan Telur Bebek Berbasis Internet of Things (IoT)," Indonesian Journal of Science, Technology and Humanities, vol. 2, no. 3, pp. 223–231, Feb. 2025.
[16] W. K. Simangunsong, C. T. H. Manurung, and I. K. L. N. Suciningtyas, "Rancang Bangun Alat Penetas Telur dengan Sistem Pengendali Suhu dan Kelembapan Menggunakan Metode Fuzzy dan Monitoring Berbasis IoT," Jurnal Integrasi, vol. 17, no. 1, pp. 70–79, Apr. 2025.
[17] R. Nazir, A. Pawawoi, M. Latif, M. I. Hamid, P. Anugrah, and E. Fitrianto, "Perancangan Sistem Smart Egg Incubator sebagai Optimalisasi Pemanfaatan Energi Terbarukan di Ngalau Baribuik, Padang," Warta Pengabdian Andalas, vol. 30, no. 2, pp. 304–313, 2023, doi: 10.25077/jwa.30.2.304-313.2023.
[18] A. Triyanto and H. Kusnadi, "Implementasi Inkubator Penetas Telur Ayam Berbasis IoT Menggunakan Aplikasi Blynk," Jurnal Teknologi Sistem Informasi dan Aplikasi, vol. 6, no. 2, pp. 47–53, Apr. 2023, doi: 10.32493/jtsi.v6i2.29068.
[19] M. A. U. Bhuiyan, M. S. Ashrafi, M. Tasnim, H. Jahan, M. Akhtaruzzaman, R. F. Baki, and S. Halder, "IoT Enabled Smart Egg-incubator with Remote Monitoring and Control System," in Proceedings of the 3rd International Conference on Computing Advancements (ICCA '24), Dhaka, Bangladesh, Oct. 17–18, 2024, pp. 1–8, doi: 10.1145/3723178.3723193.
[20] R. Rasmidatta and P. Sooraksa, "BioSim Incubator: A Non-Biological Egg Incubation Simulation Platform," Sensors and Materials, vol. 37, no. 12, pp. 5399–5410, 2025, doi: 10.18494/SAM5951.