IOT and GSM-Based Smart Egg Incubator Systems: Review Towards a Centralized Control and Monitoring Framework

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Abstract

The artificial incubation of poultry eggs is a precision-critical process requiring stable regulation of temperature, relative humidity, and egg-turning cycles. Conventional manual and semi-automated methods are labour-intensive and prone to human error, leading to significant hatchability losses. The integration of Internet of Things (IoT) and Global System for Mobile Communications (GSM) technologies provides a transformative approach for real-time remote monitoring and automated control of incubation environments. This paper critically reviews two key studies an IoT-enabled smart egg incubator with remote monitoring and control by Bhuiyan et al. (2024) and an IoT-based egg incubator with PID control and mobile application by Prabowo et al. (2024) examining their hardware architectures, software frameworks, communication protocols, control strategies, and performance outcomes. Key gaps common to both studies include the absence of GSM-based SMS alerting as a fail-safe communication layer, limited multi-sensor environmental mapping, and the lack of a centralized power management unit with battery backup.

Keywords: Egg Incubator, IoT, GSM, PID Control, Remote Monitoring, Hatchability, ESP32, Centralized Control, MQTT, Firebase.

1. Introduction

Poultry production constitutes a cornerstone of the global agricultural economy, providing an indispensable source of high-quality protein through eggs and meat. The success of commercial poultry enterprises depends critically on the artificial incubation process, which must replicate the natural brooding environment with high precision to meet the large-scale demand for day-old chicks that natural brooding alone cannot satisfy (Nugraha et al., 2021). An artificial incubator functions as a controlled chamber wherein temperature, relative humidity, and ventilation are carefully regulated to support embryonic development through to hatching (Bhuiyan et al., 2024).

Among all physical parameters governing hatchability, temperature and relative humidity are the most critical. Research consistently demonstrates that the optimal temperature for poultry egg incubation lies between 37 °C and 38 °C; any deviation from this narrow band significantly elevates the risk of embryonic mortality or the production of weak, non-viable chicks (Bhuiyan et al., 2024; Prabowo et al., 2024). Relative humidity must be maintained within a specific range to control the rate of moisture evaporation through the eggshell pores, which directly affects the development of the air cell. Automated egg turning at regular intervals is a biological necessity to prevent the developing embryo from adhering to the inner shell membrane and to ensure uniform thermal distribution across all eggs (Mujčić and Drakulić, 2021).

Traditional and semi-automated incubation systems, still widely used by small-scale poultry farmers across developing nations including India, rely heavily on manual monitoring and intervention. This approach is labour-intensive, physically demanding, and highly susceptible to human error. A momentary lapse in attention or a brief absence from the farm particularly during a critical developmental stage or a power failure can result in the irreversible loss of an entire egg batch, causing substantial economic hardship (Peprah et al., 2022). The need to overcome these limitations has driven significant research interest in the automation and remote management of egg incubation systems.

The convergence of IoT and GSM technologies presents a particularly powerful and practical solution for modernizing egg incubation management. IoT-based systems enable continuous, 24/7 acquisition of environmental data through high-precision sensors, transmittable to cloud-based platforms and accessible via mobile applications. The supplementary integration of GSM technology is especially critical for agricultural contexts in rural India, where internet connectivity is frequently unreliable. GSM modules enable the incubator to bypass the internet entirely and dispatch high-priority SMS alerts directly to the farmer's handset during critical events a robust, independent fail-safe communication layer (Lufyagila, 2021).

2. Significance of IoT and GSM Integration in Egg Incubation

The application of IoT and GSM technologies to egg incubation represents a shift from reactive, observation-based management to proactive, data-driven control. This technological integration is significant across three dimensions: precision, accessibility, and resilience.

From the perspective of precision, IoT-enabled incubators allow for continuous, high-frequency sampling of environmental parameters. Unlike human observation which is periodic and subjective automated sensor systems detect even minor deviations and trigger immediate corrective actuator responses within seconds. Advanced control algorithms such as Proportional-Integral-Derivative (PID) control can further refine this response by accounting for the thermal inertia of the heating element, preventing temperature overshooting that is characteristic of simple on/off thermostat systems (Prabowo et al., 2024).

In terms of accessibility, cloud-based IoT platforms enable farmers to supervise incubation conditions remotely using a standard smartphone. This is particularly transformative for small and medium-scale poultry operations where a single farm manager handles multiple tasks simultaneously. Real-time data visualization through graphical trend displays replaces the need for physical farm visits solely for inspection purposes (Bhuiyan et al., 2024; Rogers and Simpao, 2023).

The dimension of resilience is addressed primarily by GSM technology. In rural Rajasthan and across peri-urban Indian agricultural zones, internet connectivity is frequently intermittent. A system relying solely on Wi-Fi or cellular data notifications would be fundamentally inadequate in this context. The GSM module operates on the basic voice and messaging network which has far greater coverage to deliver SMS alerts even without an active internet connection, ensuring no critical event goes unreported regardless of connectivity conditions (Lufyagila, 2021; Peprah et al., 2022).

3. Review of Literature

3.1 Background and Motivation

Bhuiyan et al. (2024) from the Military Institute of Science and Technology (MIST), Dhaka, Bangladesh, presented an IoT-enabled smart egg incubator system with remote monitoring and control capabilities, published in the Proceedings of the 3rd International Conference on Computing Advancements (ICCA 2024). The study was motivated by the fundamental limitations of traditional egg incubation, which requires constant human intervention and is susceptible to productivity losses due to manual monitoring errors. The authors identified a gap in existing IoT incubator literature: the absence of systems offering both remote access and real-time data visualization within a role-based access framework suitable for commercial hatchery deployment.

Prabowo et al. (2024), from the Department of Electrical Engineering, Politeknik Negeri Semarang, Indonesia, published their study on an IoT-based egg incubator with a PID control system and mobile application in the JOIV: International Journal on Informatics Visualization, Volume 8, Issue 1, March 2024. Their research addressed the critical limitation of existing incubators that rely on simple manual on/off control systems, which produce inconsistent temperature profiles. The primary distinguishing contribution of this study is the application of a Proportional-Integral-Derivative (PID) control algorithm for precision temperature regulation, integrated with an IoT architecture for real-time remote monitoring at commercial incubation scale.

Several other relevant works provide important context for understanding the evolution of smart incubation technology. Peprah et al. (2022) designed a smart solar-powered egg incubator based on GSM/IoT, demonstrating the feasibility of combining both communication technologies to achieve improved hatch rates and reduced operational costs in off-grid agricultural environments. Tajul et al. (2023) found that centralized IoT monitoring reduced the time spent on physical inspections by 70% in large-scale hatchery operations, confirming the efficiency gains attainable through automation. Pandey and Pokhrel (2025) specifically emphasized the problem of thermal stratification within incubator cabinets, recommending multi-sensor arrays to detect cold spots that cause uneven embryonic development. Godinho et al. (2025) demonstrated that integrating solar backup power with centralized incubator control maintained temperature stability within 0.5 °C deviation during power interruption events.

3.2 Hardware Architecture and Component Design

Bhuiyan et al. (2024) centred their hardware design on the Arduino MKR 1010 microcontroller, selected for its integrated Wi-Fi module facilitating wireless cloud data transmission. The environmental sensing subsystem employs the DHT22 sensor for both temperature measurement (operating range: -40 °C to 80 °C, resolution: ±0.5 °C) and relative humidity measurement (range: 0–100% RH, resolution:

±0.3% RH). A 0.96-inch OLED display provides local environmental readout. The actuation subsystem comprises a 50W tungsten bulb as the heating element, a 5V DC cooling fan, an SG-996 servo motor for egg-tray tilting, and an ultrasonic mist maker as the humidifier. A three-channel relay module provides the electrical switching interface between the low-voltage MCU control signals and the mains-powered actuators. The hardware wiring follows a clearly defined pin-connection scheme where the MCU interfaces with sensors via designated digital input pins, the relay module via output pins, and the OLED display via the I2C bus.

Prabowo et al. (2024) built their hardware around the ESP32 microcontroller, valued for its dual-core processing capability and integrated Wi-Fi module, enabling simultaneous handling of PID computation, sensor acquisition, and cloud transmission. Two DHT21 temperature and humidity sensors are connected at pins D2 and D4, providing measurement redundancy. The temperature control actuator is a Positive Temperature Coefficient (PTC) ceramic heater, which offers inherent self-limiting thermal characteristics reducing the risk of thermal runaway compared to conventional resistance wire heaters. An ACS712 Hall-effect current sensor monitors the electrical current consumed by the heater, power supply, and motor a power monitoring capability not commonly found in contemporary IoT incubator designs. The incubator's mechanical structure is a five-tiered aluminum, multiplex, and aluminum foil framework with a total capacity of 500 eggs, representing a genuinely commercial-scale design. An AC motor controlled by an Omron timer relay performs automated egg-rack rotation at three-hour intervals.

Mujčić and Drakulić (2021) designed a system integrating ultrasonic humidifiers with a centralized microcontroller, finding that this method provided much faster humidity recovery after incubator door opening compared to traditional water pan evaporation methods. Nugraha et al. (2021) highlighted the importance of automated data logging for predictive maintenance, demonstrating how historical IoT data enabled early detection of gradual heater element degradation before fatal system failure. These hardware design principles collectively inform the multi-component, redundant-sensing architecture proposed for the current M.Tech research.

3.3 Software Platforms and Communication Protocols

The software architecture of the Bhuiyan et al. (2024) system is organized across three tiers: embedded firmware on the MKR 1010, a Firebase cloud backend, and an Android mobile application developed in Android Studio. Sensor data is published from the MCU to an Eclipse Mosquitto MQTT broker, from where it is relayed to the Firebase Realtime Database. Firebase Cloud Functions automate the dispatch of push notifications when environmental parameters deviate beyond predefined thresholds. The Android application implements a role-based access control (RBAC) system with three distinct user roles: Supervisor, Duty Staff, and Client. The Supervisor role grants authority to monitor all egg batches and manage personnel; the Duty Staff role provides operational control over the heating bulb, humidifier, and servo motor; and the Client role provides read-only access for customers to monitor their specific egg batches. This multi-tier role architecture makes the system genuinely scalable for commercial hatchery deployment.

The software architecture of the Prabowo et al. (2024) system follows a four-layer IoT model: Device (ESP32), Connectivity (Wi-Fi), Cloud Platform (Firebase Realtime Database), and User Application (Kodular-developed Android app). The ESP32 transmits sensor data to Firebase using HTTP or WebSocket protocols via the Firebase API. Firebase's listener capability ensures real-time propagation of data changes to client applications. The Kodular mobile application provides users with real-time temperature, humidity, and current readings, graphical visualizations, and automatic push notifications for measurement anomalies. Users can set desired temperature and humidity levels remotely and monitor incubator status from their smartphones. The average data transmission latency from the ESP32 node to Firebase was measured at 31.3 milliseconds across 40 consecutive samples, with individual values ranging from 12 ms to 88 ms, confirming the suitability of this architecture for near-real-time monitoring.

Rogers and Simpao (2023) implemented a web-based monitoring system and found that centralized server management allowed control of multiple incubator units from a single administrative interface, emphasizing the importance of centralized data management for large-scale production where individual unit tracking becomes difficult. Balasingam et al. (2022) evaluated the cost-effectiveness of open-source hardware for poultry automation, finding that a custom IoT system could be developed at 40% of the cost of industrial-grade incubators while maintaining comparable environmental control precision, making the technology accessible to small-scale poultry entrepreneurs.

3.4 Control Strategies and Algorithms

Bhuiyan et al. (2024) employed a threshold-based hysteresis switching strategy for both temperature and humidity control. The incubation temperature is targeted at 35 °C with an upper limit of 37 °C. For humidity, the humidifier is activated when relative humidity falls to 50% or below and is deactivated once it reaches 65%; the cooling fan is then switched on to bring humidity back into range. Egg turning is scheduled at two-hour intervals with the servo motor tilting the tray to a 45° angle. While operationally effective for the prototype scale, this binary on/off control approach is susceptible to temperature oscillation around the setpoint due to the thermal inertia of the heating element, a well-documented limitation of simple threshold control in enclosed incubation environments.

Prabowo et al. (2024) employ a significantly more sophisticated PID control algorithm for temperature regulation, representing the primary technical differentiator of their study. The setpoint is configured at 38 °C. The PID controller receives the error signal the difference between the setpoint and the measured temperature and computes a corrective output as a Pulse Width Modulation (PWM) signal that continuously modulates the power supplied to the PTC heater. The tuning parameters employed are Kp = 10 (Proportional gain), Ki = 3 (Integral gain), and Kd = 8 (Derivative gain), determined using a combination of the Relay Feedback method and Ziegler-Nichols formulas. The proportional term responds to the current error magnitude; the integral term eliminates steady-state offset; and the derivative term provides predictive damping that reduces overshoot. The combined effect produces a temperature control response that is faster, more stable, and more precise than on/off switching. Humidity control, however, remains threshold-based in this system a design inconsistency that the proposed research aims to address through a unified control logic framework.

Lufyagila (2021) demonstrated that for farmers in areas with poor or intermittent internet connectivity, GSM-based SMS alerts are significantly more reliable than IoT push notifications, as they do not require an active data plan or Wi-Fi signal to reach the farmer's mobile device. This finding directly motivates the dual-layer control and communication architecture proposed for the current research, wherein PID-based environmental control is complemented by a GSM hardware fail-safe layer operating independently of internet availability.

3.5 Performance Evaluation and Reported Outcomes

Bhuiyan et al. (2024) evaluated system performance through formal usability testing with a diverse cohort including students, housewives, farmers, and poultry farmers, using a within-group experimental design. Each participant performed standardized tasks including real-time data monitoring, checking push notifications, and remotely controlling temperature, humidity, and egg-turning mechanisms.

Prabowo et al. (2024) validated their system through physical parameter measurement rather than user-centric testing. Temperature measurements recorded at 30-minute intervals confirmed that the PID controller successfully maintained the internal temperature at the 38 °C setpoint throughout the incubation session, with no significant overshoot detected. Humidity remained consistently within the desired range of approximately 80% across all recorded intervals. The DHT21 sensor achieved a 90% success rate in correctly detecting the target temperature and humidity conditions. Actuator motor testing confirmed reliable rack rotation at every scheduled three-hour interval across all five tested time points, with each rotation cycle completing in 40 seconds as programmed. Current sensor data showed stable electrical consumption: 8.33 A for the PTC heater, 0.53–0.64 A for the power supply, and 0.09 A for the motor.

Table 1: Comparative Analysis of Reviewed Studies

Feature / Parameter	**Bhuiyan et al. (2024)**	**Prabowo et al. (2024)**
Microcontroller	Arduino MKR 1010	ESP32
Primary Sensor	DHT22 (single unit)	DHT21 (dual unit)
Temperature Control	On/Off hysteresis (35–37 °C)	PID (Kp=10, Ki=3, Kd=8)
Humidity Control	Threshold (50–65% RH)	Threshold (~80% RH)
Egg Turning	Servo (SG-996), 2 hr interval, 45°	AC Motor, Omron Timer, 3 hr interval
Communication	MQTT → Firebase (Wi-Fi)	HTTP/WebSocket → Firebase (Wi-Fi)
GSM / SMS Alerting	Not Implemented	Not Implemented
Mobile Application	Android Studio, RBAC	Kodular
Power Monitoring	Not Implemented	ACS712 Current Sensor
Battery / Power Backup	Not Implemented	Not Implemented
Egg Capacity	4 eggs (prototype)	500 eggs (commercial scale)
Hatchability Data Reported	Not Reported	Not Reported

Results demonstrated high operational accuracy across most tested parameters. Servo motor activation and deactivation both recorded 98% success rates; humidifier control achieved 96% in both on and off conditions; and the overall task completion rate was approximately 90%. Users accomplished all tasks with 100% accuracy without requiring assistance, confirming an exceptionally user-friendly interface design. The lowest success rate of 90% was recorded for Fan Off, attributed to power distribution issues in the prototype's relay module.

Table 2: Usability Testing Results - Bhuiyan et al. (2024)

Test Case	No. of Trials	Successes	Success Rate	Remarks
Humidifier Turned On	50	48	96%	Satisfactory
Humidifier Turned Off	50	48	96%	Satisfactory
Bulb Turned On	50	47	94%	Power distribution issue
Bulb Turned Off	50	49	98%	Satisfactory
Servo Motor Activation	50	49	98%	Satisfactory
Servo Motor Shutdown	50	49	98%	Satisfactory
Fan On	50	47	94%	Power distribution issue
Fan Off	50	45	90%	Power distribution issue

Table 3: Key Performance Metrics - Prabowo et al. (2024)

Performance Parameter	Measured Value	Remarks
Temperature Setpoint	38 °C	Maintained stably by PID throughout test
Sensor Detection Success Rate	90%	DHT21 detecting 38 °C and 77–84% RH
Humidity Range	~80%	Consistent across 30-min interval recordings
Motor Rotation Interval	Every 3 hrs	40 seconds per rotation cycle
Motor Test Success Rate	5/5 (100%)	All scheduled activations successful
Avg. Cloud Upload Latency	31.3 ms	Range: 12–88 ms across 40 samples
Incubator Egg Capacity	500 eggs	Five racks of 100 eggs each

4. Research Gaps and Design Implications for the Proposed System

The critical review of the surveyed literature reveals five primary gaps that the proposed GSM and IoT-based centralized control and monitoring system for egg incubators at MPUAT is specifically designed to address.

4.1 Absence of GSM-Based Fail-Safe Communication

Neither study reviewed incorporates a GSM module for SMS-based alerting, which is the most significant gap given the deployment context of rural Indian poultry farms with unreliable internet connectivity. Peprah et al. (2022) and Lufyagila (2021) have both demonstrated the superior reliability of GSM-based SMS alerts over internet-dependent push notifications in such environments. The proposed system will integrate a dedicated GSM module (SIM A7670 LTE) that operates independently of internet connectivity. Critical events including sensor threshold breaches, power outage detection, and system fault conditions will trigger immediate SMS alerts to the registered farmer's mobile number, providing a dual-layer communication architecture in which IoT cloud handles normal monitoring while GSM SMS handles emergency alerting.

4.2 Single-Sensor Monitoring and Thermal Stratification

Both surveyed systems use limited sensor deployments that cannot adequately characterize the thermal distribution within the incubator volume. Pandey and Pokhrel (2025) specifically documented that thermal stratification within incubator cabinets causes cold spots in corner positions, leading to delayed or failed hatching for eggs in those positions. A single DHT22 or even dual DHT21 sensors fail to account for this spatial variability. The proposed system will deploy a multi-point sensor array including DS18B20 temperature probes and SHT4x combined temperature-humidity sensors at multiple vertical tray positions, generating averaged and position-specific environmental readings to eliminate stratification-induced measurement error.

4.3 Absence of Power Management and Battery Backup

Both surveyed systems lack any provision for managing power continuity, which is the single most critical infrastructure requirement for an egg incubator. Even a brief heating interruption during sensitive embryonic developmental phases can cause irreversible damage. Godinho et al. (2025) demonstrated that integrating a backup power source with a centralized incubator control unit can maintain temperature within 0.5 °C deviation during extended power interruptions. The proposed system will include a dedicated power management unit with battery backup that automatically activates on mains power failure while simultaneously triggering a GSM SMS alert to the farmer.

4.4 Lack of Hatchability Performance Data

Neither study reports actual hatchability efficiency as an outcome measure, which is the definitive biological metric for assessing incubation system performance. Bhuiyan et al. (2024) report only functional and usability testing outcomes, while Prabowo et al. (2024) report only physical parameter stability data. The explicitly includes Hatchability Efficiency ($HE = Nh/Nt \times 100$) as a primary dependent variable in its performance evaluation plan, alongside temperature stability and GSM alert reliability, providing a biologically meaningful and economically relevant measure of overall system effectiveness.

4.5 Effect of Vertical Tray Position on Incubation Parameters

Neither surveyed study evaluates the effect of vertical tray position within the incubator cabinet on environmental parameter stability or hatching outcomes, despite this being a well-recognized factor in multi-tier incubator design. The proposed research includes Vertical Tray Position as an independent variable with three levels in its experimental design, recognizing that temperature and humidity may vary systematically between upper, middle, and lower tray positions due to convection currents and differential proximity to the heating element.

5. Contribution of Reviewed Studies to the Proposed Research Design

Despite their limitations, the surveyed studies make substantial and direct contributions to the design of the proposed system. From Bhuiyan et al. (2024), the proposed research validates the principle of role-based access architecture for eventual commercial deployment, confirms the suitability of DHT-series sensors, relay modules, and Firebase for cloud data management, and adopts the finding that a well-designed mobile interface makes complex IoT control accessible to non-technical smallholder farmers. Their experimental finding of 100% user task accuracy without assistance is a benchmark for the interface design of the proposed system.

From Prabowo et al. (2024), the proposed research adopts the ESP32 microcontroller as the central processing unit, validated by its demonstrated cloud communication performance of 31.3 ms average upload latency and its superior processing capability for simultaneous PID computation and wireless transmission. The PID control philosophy for temperature management is adopted as the core algorithm for the proposed system's centralized processing logic. The ACS712 current monitoring approach informs the proposed system's power management unit design. The commercial-scale five-tiered incubator framework confirms the structural feasibility of the proposed multi-tray evaluation methodology.

Taken together, the surveyed literature validates the use of a two-channel or three-channel relay module for actuator switching, the Firebase platform for real-time data storage and notification, and MQTT or HTTP protocols for MCU-to-cloud communication. These are proven, cost-effective components and protocols appropriate for the Indian rural agricultural deployment context.

6. Conclusion

This paper has critically reviewed two significant studies on IoT-based egg incubator systems Bhuiyan et al. (2024) from Bangladesh and Prabowo et al. (2024) from Indonesia aimed at developing a GSM and IoT-based centralized control and monitoring system for egg incubators.

Both studies make meaningful contributions to the field. Bhuiyan et al. (2024) demonstrate a commercially viable, user-friendly, role-based IoT management platform with strong usability validation, while Prabowo et al. (2024) demonstrate superior temperature precision through PID control, commercial-scale engineering, and a novel power monitoring capability. Together, these studies confirm that IoT-based automation of incubation parameters is technically feasible and produces measurable improvements in operational efficiency and user experience over manual methods.

However, both studies share critical limitations that are particularly consequential for the Indian poultry farm context: a complete absence of GSM-based SMS alerting as an internet-independent fail-safe, the lack of battery-backed power management, insufficient multi-point sensor coverage, and the absence of reported hatchability performance data. The proposed MPUAT research is specifically designed to address each of these gaps, integrating a SIM A7670 GSM module, DS18B20 and SHT4x multi-sensor array, a Nextion HMI display for local monitoring, battery-backed power management, and a formal three-variable experimental design evaluating temperature stability, GSM alert reliability, and hatchability efficiency.

The proposed system represents not merely an incremental improvement over the reviewed designs, but a comprehensive, resilient, and context-appropriate solution for precision poultry management under Indian agricultural conditions. It aims to bridge the digital divide in precision farming by providing a low-cost, high-reliability, dual-communication-layer monitoring framework specifically tailored to the socioeconomic and infrastructural realities of the Indian poultry sector. Future directions should include the incorporation of machine learning algorithms for predictive parameter control, candling-based egg viability detection through computer vision, and multi-unit centralized management through a single administrative web dashboard.

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