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Design and Implementation of an Intelligent Chicken Egg Incubation System Using Light and Temperature Sensors Based on Arduino UNO R3

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Abstract

This research aimed to develop an intelligent chicken egg incubation system that maintained stable environmental conditions using light and temperature sensors controlled by an Arduino UNO R3. The system addressed the problem of unstable temperature and humidity in traditional manual hatching, which often resulted in low hatchability rates. The proposed incubator integrated a DHT22 sensor, LDR, keypad, relay module, servo motors, and a microcontroller that automatically regulated heating, ventilation, and egg-turning mechanisms. The prototype was tested through several stages, including sensor responsiveness, actuator performance, security verification, and a comparative incubation experiment. The system was then evaluated using two groups of eggs: an experimental group incubated using the automatic system and a control group incubated manually without environmental regulation. Test results showed that all system components operated consistently, with temperature and humidity maintained within the ideal range for incubation. Embryos in the experimental group exhibited normal growth until hatching, while all embryos in the control group failed to develop due to extreme environmental fluctuations. These findings demonstrated that the automated incubator successfully created a controlled and stable environment capable of supporting healthy embryo development.

Keywords: Arduino UNO R3; Egg incubator; DHT22; LDR; Relay; Servo motor; Keypad.

1. Introduction

Demand for poultry products in Indonesia continues to increase, as reflected in chicken consumption, which rose from 7.96 kg in 2022 to 8.20 kg per capita in 2023[1]. Eggs and chicken meat are the main sources of protein for the population, and the national free meal program is projected to increase the demand for poultry production [2], [3]. However, many small-scale farmers still use manual hatching methods, resulting in unstable temperatures and lighting, which leads to low hatchability rates. This situation highlights the need for an affordable and reliable smart incubation system.

Previous studies have developed various automatic hatching machines, such as microcontroller-based temperature control [4], [5], finite state machine logic [6], and fuzzy-based adaptive control [7], [8]. However, most studies only focus on temperature and humidity without integrating light sensors, and there is minimal comparative evaluation between controlled and uncontrolled conditions. This study proposes an Arduino UNO R3-based smart chicken egg incubation system that utilizes light and temperature sensors for closed-loop environmental control. The system was then tested using two groups: the

Experimental Group, consisting of five chicken eggs hatched using an automatic incubator designed by the researcher, and the Control Group, consisting of five chicken eggs hatched manually without an incubator. Both groups were observed during the incubation period to examine embryo development and differences arising from variations in environmental conditions. The innovation of this research lies in the combination of light and temperature control in the incubator and the application of a comparative experimental design that provides practical evidence of the effect of environmental stability on embryo development.

2. Material and methods

The research stages in Figure 1 begin with problem identification regarding instability of temperature and humidity in traditional hatching, followed by a literature review to establish the theoretical basis for automated incubation and sensor-based control. Data collection through field observation identified functional requirements for system development. The system design integrates DHT22, LDR, keypad 4×4, relay modules, servo motors, and Arduino UNO R3 as described in the block diagram and circuit analysis. The prototype was tested for sensor accuracy, light detection, PIN verification, and actuator performance. Additionally, the system was implemented on two groups of eggs: an Experimental Group of five eggs incubated using the designed automatic system and a Control Group of five eggs incubated manually without an incubator, with periodic inspection of embryo development. The analysis and conclusion confirmed system stability and effective automated incubation performance.

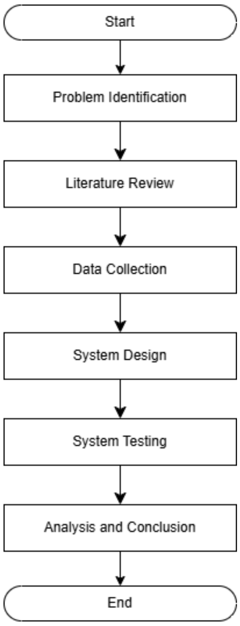


Figure 1: Research Flowchart

2.1 System Architecture

The system integrates Arduino UNO R3, a DHT22 temperature and humidity sensor, an LDR light sensor, keypad 4×4, relay module, servo MG996R, servo SG90, DC fan, incandescent lamps, and LCD I2C 20×4. Input blocks include DHT22, LDR, and keypad. The microcontroller executes control logic and drives output elements: heating lamps, fan, servo mechanisms, and LCD.

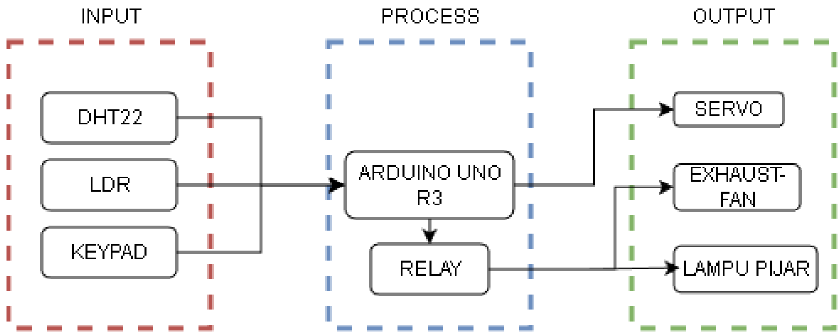


Figure 2: Block Diagram

The flowchart in Figure 3 illustrates the automatic workflow of the incubator, which begins with the initialization of components. The system then continuously reads the temperature, humidity, and incandescent lamp status. Based on the readings, the system determines whether the temperature is below 37°C or above 39°C to turn on the heating lamp or cooling fan, while displaying the data in real time. If the light is active, the servo will move the egg tray to simulate egg turning. In parallel, the security mode verifies the PIN entered by the user; the correct PIN unlocks the incubator door, while an incorrect PIN keeps the door locked. The entire process, from setting the heater, fan, tray movement, to door control, runs automatically until the system reaches a stable operating condition.

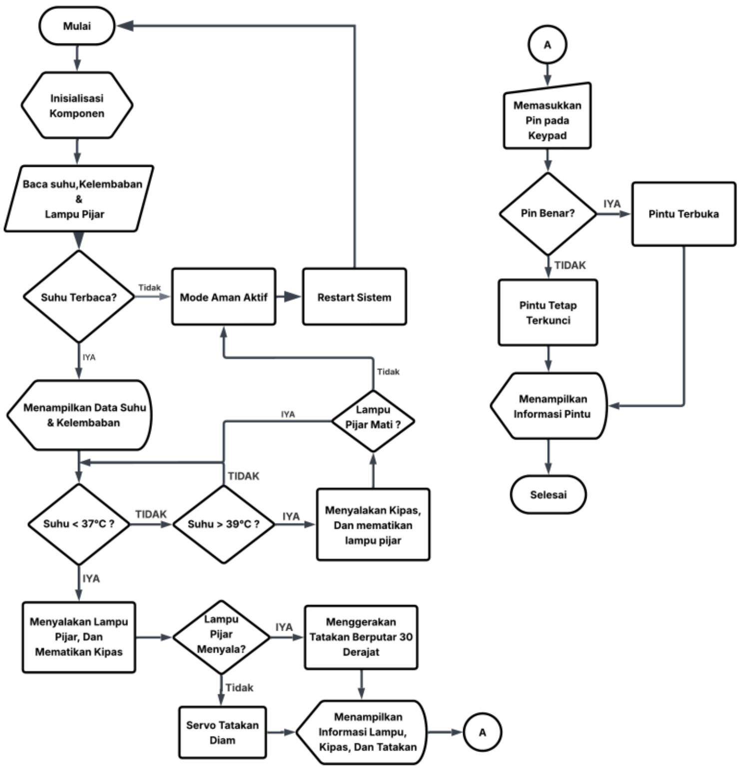


Figure 3: System Flowchart

2.2 Hardware and Electrical Design

The physical enclosure follows a 3-D design created using Blender. The system places the heating lamps on the upper chamber, egg tray in the mid-section driven by MG996R, humidity water tray at the bottom, DHT22 and LDR inside the chamber, and LCD plus keypad on the exterior panel.

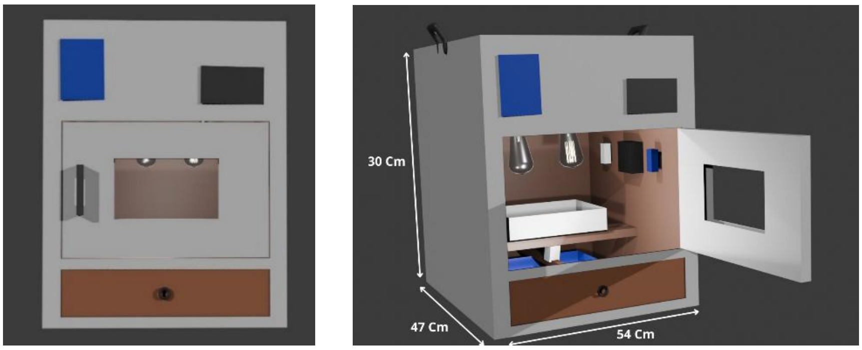


Figure 4: 3D Incubator Design

2.3 Electrical Design

Supply includes 5V DC for Arduino and sensors, external power for MG996R, and 220V AC for heating lamps routed via a 2-channel relay. The fan uses a 9V supply. Signal routing is as documented: DHT22 on digital pin 7, LDR on A0, keypad rows on pins 10–13 and columns on A1–A4, servo pins on 5 and 6, relays on pins 8 and 2.

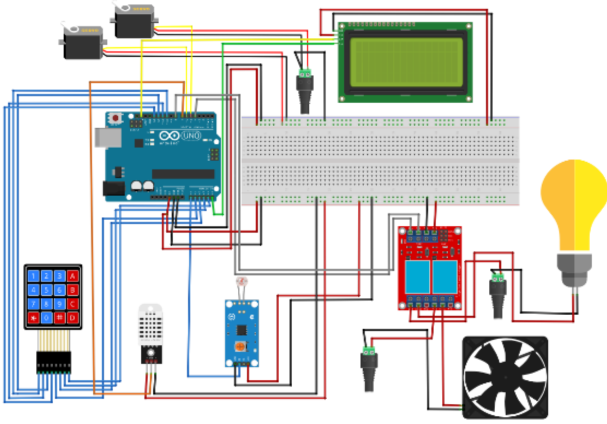


Figure 5: Wiring Diagram

2.4 Equipment and Materials Used

The equipment used in this research was carefully selected based on its functional role in supporting the development of the automatic egg incubator system, with detailed specifications presented in Table 1.

Table 1: Equipment Used

Equipment	Spesification
Arduino UNO R3	Powered by an ATmega328P microcontroller, the Arduino UNO R3 operates at 5V logic, with a recommended external supply of 7–12V, and a 16 MHz clock speed. It provides 14 digital I/O pins (6 supporting PWM), 6 analog input pins, 32 KB Flash memory (0.5 KB bootloader), 2 KB SRAM, 1 KB EEPROM, and a USB Type-C interface for programming and power
DHT22 Sensor	Operates at 3.3–5.5V with 0.3 mA active and 60 µA standby current, featuring a polymer humidity capacitor and digital one-wire

Equipment	Spesification
	output. Measures 0–100% RH (±1% accuracy) and −40°C to 80°C (±0.5°C accuracy) with a 16-bit resolution and ~2 s sampling interval.
LDR Light Sensor	A cadmium-sulfide (CdS) photoconductive resistor with resistance ~500Ω (bright) to >200 kΩ (dark). Produces an analog voltage output proportional to light intensity and operates with a response time of 20–100 ms, suitable for illumination detection within the incubator
Keypad 4×4 Matrix	Consists of 16 keys arranged in a 4-row × 4-column matrix, operating at 3.3–5V. Uses row-column scanning to generate digital signals for each keypress and supports long-life membrane switches rated up to 1 million presses.
Relay Module (2-Channel)	A 5V DC opto-isolated relay module with LOW-trigger activation, capable of switching loads up to 10A (AC) or 5A (DC). Equipped with NO/NC/COM terminals per relay and LED indicators for channel status.
Motor Servo SG90	A micro-servo operating at 4.8–6V, offering 1.8 kg·cm torque, 0–180° rotation, and 0.1 s/60° speed. Lightweight at 9 g, equipped with plastic gear system and a 3-wire PWM control interface (VCC, GND, Signal)
Motor Servo MG996R	A high-torque metal-gear servo operating at 4.8–7.2V with torque ratings of 9.4–11 kg·cm, 0–180° rotation, and 0.17 s/60° speed. Features durable metal gears, a stronger motor, and standard PWM control.
5V DC Fan	A DC brush motor fan powered by direct-current supply, providing adjustable rotational speed based on input voltage. Produces steady airflow for temperature regulation and features low-power operation suited for continuous cooling tasks
Heat Lamp	A filament-based incandescent bulb producing heat and visible light through resistive heating. Operates on AC supply and provides stable thermal output, making it suitable as a heating source in non-contact incubation applications.
LCD I2C 20×4	A character display module supporting 20 columns × 4 rows, using I2C communication with SDA–SCL lines. Operates at low power and provides clear alphanumeric output for real-time system monitoring.

2.5 Software

This study uses three main software programs, namely Arduino IDE, Fritzing, and Blender 3D. Arduino IDE is used to write, compile, and upload programs to the Arduino UNO R3 microcontroller using the C/C++ language. Fritzing was used to design circuit schematics and component layouts visually, making the assembly process more structured and accurate. Meanwhile, Blender 3D was used to create and visualize the incubator model design in three dimensions, facilitating the planning of the physical appearance of the device prior to the manufacturing process.

3. Results and discussion

To evaluate the overall performance of the incubator system, several tests were conducted, including temperature and humidity sensor testing, LDR testing, keypad and servo door testing, and incubation observation for the experimental group. The results show that all components operated properly and supported stable incubation conditions, while the experimental eggs developed normally until hatching.

3.1 Temperature and Humidity Testing

Temperature and humidity testing was conducted by monitoring the performance of the DHT22 sensor during the incubation process, as shown in Table 2. This test assessed the sensor's response to temperature changes inside the incubator and the suitability of incandescent lamp and fan activation based on system setting limits.

Table 2: DHT22 Sensor Evaluation

Time	Temperature (°C)		Response Time (s)	Humidty (%RH)	Incandescent Lamp	Fan
	Initial	Change				
17.34	0°C	34.5°C	03.80	72	ON	OFF
17.36	37.5°C	37.7°C	01.53	62	ON	OFF
17.38	39.2°C	39°C	01.57	60	OFF	ON
17.40	37.9°C	37.5°C	01.52	63	OFF	ON
17.42	36.7°C	37°C	01.56	61	ON	OFF
17.44	38.5°C	38.8°C	01.54	59	ON	OFF

Based on the evaluation results in Table 2, the DHT22 sensor showed accurate and responsive performance in reading changes in temperature and humidity inside the incubator. The average response time ranged from 1.53 to 1.57 seconds, with the exception of initial measurements, which took longer due to the sensor initialization process. The incandescent lamp and fan activation patterns also correspond to the system logic, where the lamp turns on when the temperature is below the ideal limit, and the fan activates when the temperature exceeds 39°C. The measured humidity is in the range of 59–72%, which is still within the ideal range for the hatching process. Overall, this table shows that the DHT22 is capable of supporting stable temperature and humidity control in an automatic incubator system.

3.2 Light Testing

Light testing was conducted to ensure the sensor's ability to detect changes in light intensity from the incandescent lamp inside the incubator. The data in Table 3 shows how the sensor responds to dark and light conditions and their impact on servo activation.

Table 3: LDR Sensor Evaluation

Time	Light Condition		Sensor Reading	Response Time (s)	Tray Servo
	Initial	Change			
17.58	Bright	Bright	Light Detected	04.11	Moving
18.04	Dark	Dark	Light Not Detected	01.15	Still
18.09	Dark	Bright	Light Detected	01.13	Moving
18.13	Bright	Dark	Light Not Detected	01.14	Still
18.18	Dark	Bright	Light Detected	01.17	Moving
17.58	Dark	Bright	Light Detected	04.11	Moving

Based on the results in Table 3, the LDR sensor is capable of detecting changes in light with a fast response, averaging around 1.1–1.2 seconds, except for the initial reading which takes longer due to the initialization process. Servo activation is also consistent, moving when light is detected and stopping when it is dark. This shows that the LDR works accurately and can be relied upon as a trigger for tray movement in an automatic incubator system.

3.3 Keypad and Door Testing

Keypad and door testing was conducted to ensure that the incubator security system could verify the PIN correctly and control the door servo according to the specified logic. Table 4 shows how the PIN input is validated by the system and how the servo responds to each condition, whether the PIN is correct or incorrect.

Table 4: Keypad Authentication

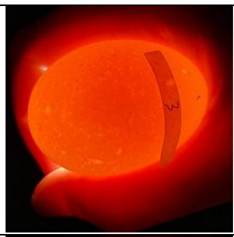
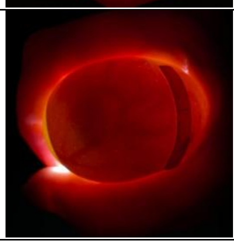
Input PIN	Verification Status	Door Servo Movement	Response Time (ms)	Description
”8566”	Incorrect	Still	0	Door Remains Locked
”2338”	Incorrect	Still	0	Door Remains Locked
”0000”	Correct	Rotates 90 °	00.19	Door Opens
”0000”	Correct	Rotates90 °	00.20	Door Locks Again
”2706”	Incorrect	Still	0	Door Remains Locked

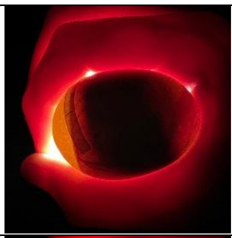
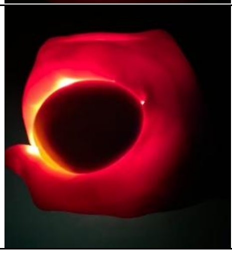
The results in Table 4 show that the PIN verification system works consistently, where each incorrect PIN causes the door to remain locked, while the correct PIN triggers the servo to move 90° to open or close the door. The very fast response time, which is around 0.19–0.20 ms, proves that the keypad and door servo function properly and are able to support the incubator's security features effectively.

3.4 Incubation Observation Data

Embryo development was monitored periodically on days 1, 7, 14, 21, and 23 to observe changes in average size and visual condition of the embryos during incubation in the experimental group. These observation data are recorded in the form of embryo size growth, candling documentation, and biological development status, then visualized through graphs to show the growth trends of each egg. This approach provides a comprehensive picture of the consistency of embryo development during the incubation period and the effectiveness of the automatic incubator system used.

Table 5: Incubation Observation Data for Experiment Group

Day	Average Egg Size Growth (mm^2)	Documentation	Embryo Status
1	~8 mm^2		No progress yet
7	~255 mm^2		The embryo is moving and growing normally

Day	Average Egg Size Growth (mm²)	Documentation	Embryo Status
14	~1044 mm²		The embryo fills more of the egg space
21	~2072 mm²		The organs should be fully developed and ready to hatch
23	~2140–2155 mm²		Embryo hatches

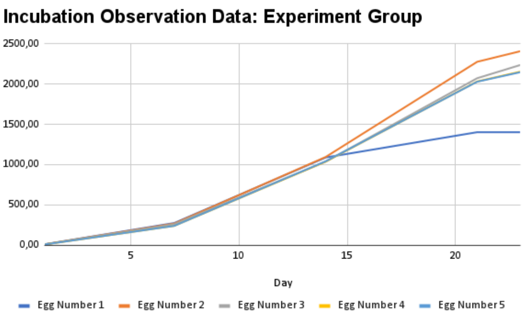


Figure 6: Incubation Observation Data for Experiment Group

Based on Table 5 and Figure 6, all embryos in the experimental group showed a significant increase in size from day 1 until close to hatching day. Growth was most rapid during the period from day 7 to day 21, in line with the phase of organ formation and filling of space within the egg. By day 23, most embryos had reached optimal size and showed signs of readiness to hatch, with one embryo recorded as having successfully hatched. These findings confirm that the automatic incubator system is capable of maintaining stable incubation conditions that support normal embryo development.

Meanwhile in the control group, eggs were placed in cardboard boxes lined with straw and heated by incandescent lamps without any temperature or humidity control system. The unstable environmental conditions caused extreme temperature fluctuations that did not meet the ideal range for chicken embryo incubation. As a result, all eggs in the control group showed developmental failure and were declared dead on the first day of observation. These findings emphasize the importance of consistent temperature and humidity control during the incubation process to maintain embryo viability.

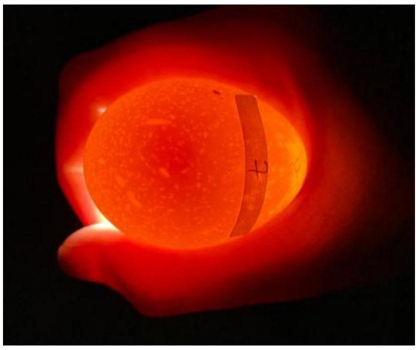


Figure 7: One of the Eggs in the Control Group on Day 1

4. Conclusion

This research successfully developed an intelligent egg incubator system utilizing Arduino UNO R3 integrated with DHT22, LDR, keypad authentication, relay-controlled heating, ventilation, and servo-based egg turning to maintain stable incubation conditions. The system consistently regulated temperature and humidity within the ideal range, enabling normal embryo development in the experimental group while the control group showed complete developmental failure due to uncontrolled environmental fluctuations. These findings demonstrated that the proposed system effectively supported a healthy incubation environment and offered a reliable, low-cost solution for small-scale poultry producers who still depend on manual hatching methods. The integration of automated environmental control, security features, and responsive actuator performance shows strong potential for wider application in rural or home-based poultry operations. Future enhancements may include remote monitoring, backup power systems, and more adaptive control algorithms to further increase system reliability, user convenience, and overall hatchability performance.

Author contribution

Author 1: hardware assembly, testing. Author 2: system design, data acquisition. Author 3: analysis, manuscript drafting. Author 4: programming, schematic development, documentation. Author 5: research supervision and manuscript review.

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