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Design and construction of an Arduino-based baby incubator simulator using IoT

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ABSTRACT

This study aims to create a baby incubator simulator equipped with an internet of things (IoT)-based temperature control system using Arduino UNO. We use a DHT22 sensor to measure temperature and humidity, as well as fuzzy logic to ensure more accurate and responsive temperature control. The Thinger.io platform enables real-time monitoring and control of the incubator, providing flexibility and ease of supervision. With fuzzy logic, the temperature control system can handle changes and uncertainties in the incubator environment, providing a smoother response compared to traditional on-off methods. Testing shows that this system has a very low error rate, with an error value of only 0.97%, meaning that the measured temperature is almost identical to the actual conditions inside the incubator. Additionally, the authors used mice as a model for premature infants in the testing. The results showed that the mice's body temperature increased gradually and stably in line with the incubator conditions, reaching the desired temperature within 90 minutes. This demonstrates that our temperature control system is capable of maintaining optimal environmental conditions for premature infants.

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1. INTRODUCTION

Gestational age is a crucial factor that can affect fetal survival and quality of life after birth. A pregnancy that lasts between 37 and 41 weeks is considered full-term, while a birth that occurs before the gestational age reaches 37 weeks is called a premature birth [1]. Various factors can cause a baby to be born prematurely, including the mother's poor lifestyle, uterine abnormalities, and other factors. These factors affect neonatal health, such as temperature, birth weight, heart rate, and bilirubin levels in the baby's blood [2]. Globally, approximately 0.4% of births occur during the preterm period, leading to serious neonatal morbidity with high mortality rates. In the United States, over 40% of premature infant deaths are caused by births that occur earlier [3]. According to Dr. Siti Nadia Tarmizi from the Indonesian Ministry of Health, reducing the rate of premature births can be achieved through prevention before the baby is born. However, to treat premature babies, the use of infant incubators is an effective solution.

The use of a DHT22 sensor is one way to monitor the temperature and humidity inside an incubator. The DHT22 is a digital sensor that measures humidity and relative temperature using a capacitor and thermistor and produces a digital signal that is output on the data pin. This sensor has a low percentage error rate compared to other temperature and humidity sensors [2]. The optimal temperature in an incubator ranges from 31 °C to 36 °C, with adjustments based on the baby's weight. The heavier the baby's body, the lower the required incubator temperature [1]. The development of baby incubators with internet of things (IoT) technology enables real-time monitoring and control of sensors, as demonstrated in research [4] using a remote-control system based on Arduino UNO and IoT.

This study uses mice as a model in the development of temperature control in infant incubators. Mice have many similarities with humans, such as in the immune system and blood composition, although there are some important differences. For example, mice have lymphoid tissue in the bronchi and blood dominated by lymphocytes, unlike humans. With these similarities, mice can serve as an effective and ethical research model [5]. Based on the above description, this study conducted the planning and design of a temperature and humidity sensor control system on a baby incubator simulator. An Arduino UNO was used as the brain of the sensor, with the internet for real-time monitoring and control of the sensor [6].

2. METHOD

2.1. Research review

This study aims to develop a baby incubator simulator [7] equipped with an IoT-based temperature control system using Arduino UNO. The initial stage involved designing an incubator chamber equipped with a heater, fan, and DHT22 sensor to monitor temperature and humidity in real time [8]. Incubator condition data is transmitted and displayed via the Thinger.io platform, facilitating remote monitoring and control. This system can automatically maintain stable incubator temperature [9] according to the needs of premature infants over an extended period. To improve the accuracy of temperature control, this study applies the fuzzy logic control method [10]. This approach was chosen because it is more adaptive than conventional on-off methods and can respond to uncertainties and environmental changes within the incubator. Using fuzzy logic [11], the control system can generate smoother and more stable control actions, thereby minimizing errors between the desired temperature and the actual temperature.

The testing was conducted using mice [12] as a biological model representing premature infants [5], to avoid ethical issues [13] associated with the use of human infants. The results of the experiment showed that the increase in the body temperature of the mice was stable and in line with changes in the incubator temperature, reaching the expected value within 90 minutes. This proves that the combination of Arduino UNO, fuzzy logic, and the Thinger.io platform can produce an effective and reliable temperature control system in a baby incubator simulator.

2.2. Research design

This methodological process began with gathering information from various literature related to baby incubators, IoT technology, and the use of Arduino UNO. After that, the problems to be solved were clearly formulated. Next, the planning and design of the baby incubator simulator was carried out carefully. The DHT22 temperature and humidity sensor [14] is then calibrated and tested to ensure the accuracy of its data, which is integrated with the Thinger.io platform [15]. If the temperature is within the range of 29-36 °C, the sensor will be activated; otherwise, if it is outside this range, the sensor will be deactivated. Finally, the system data is evaluated to assess the performance of this device, followed by conclusions and recommendations for further development. To clarify the methodology of this research journal, all of this is presented in a flowchart as shown in Figure 1. The following are the supporting tools needed to support this research: hardware includes Arduino R3 built-in Wi-Fi ESP8266, DHT22 sensor, heater, blower, relay, breadboard, power supply, and laptop. Meanwhile, software includes Arduino IDE and Thinger.io.

2.3. System testing

The following tests will be conducted in this research:

i) Testing of temperature control devices against thermometers: this test aims to evaluate the accuracy of temperature control devices applied to incubators by comparing sensor readings with a calibrated standard thermometer in an 80:20 ratio. Similar comparative validation methods have shown in neonatal incubators that such testers can achieve over 98 % accuracy when benchmarked against reference instruments [16]. Another study demonstrated the reliability of prototype incubator analyzers, achieving over 98 % temperature accuracy in lab-scale testing [17].
ii) Testing changes in mouse body temperature in response to changes in temperature: this test is conducted to evaluate physiological responses, changes in mouse body temperature will be monitored when the incubator is set to certain temperature levels. Previous studies characterizing core body temperature in mice during and after temperature exposure provide a strong methodological precedent [18]. Accurate body temperature measurement techniques in mice are well-documented and essential for reliable data

capture [19]. Additionally, studies demonstrating temperature variation in mice under environmental stress reinforce the sensitivity of mouse thermoregulation systems to ambient changes [20].

This system block diagram illustrates an IoT–based temperature control system using an Arduino R3 with a built-in ESP8266 module. The temperature sensor continuously measures the ambient temperature and sends the data to the Arduino as the main control unit. The Arduino processes this data and communicates with the Thinger.io platform to enable remote monitoring and control via the internet. Based on the temperature readings and user-defined settings, the Arduino sends control signals to the heater driver and fan driver. These drivers then activate the heater or fan to regulate and maintain the desired temperature conditions, as shown in Figure 2.

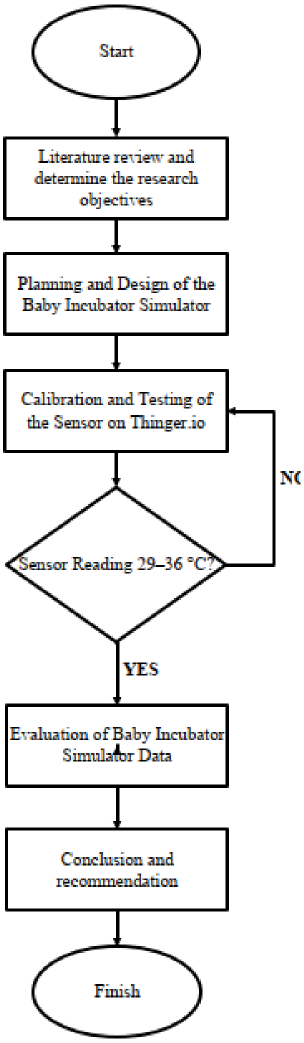

Figure 1. Research flowchart

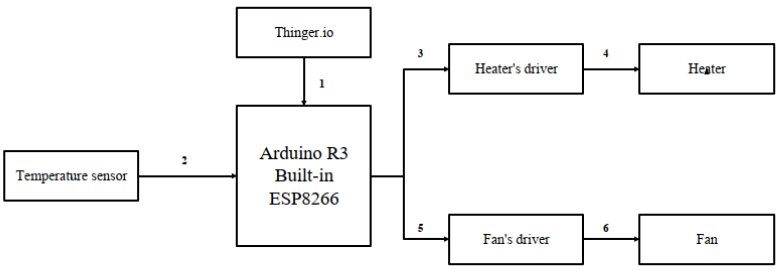

Figure 2. System block diagram

The temperature control system depicted in the block diagram uses Arduino R3 with built-in ESP8266 to function as a control center for regulating the ambient temperature. The DHT22 temperature sensor measures the temperature periodically and sends data to the Arduino. The Arduino then uses a fuzzy logic algorithm to calculate the required pulse width modulation (PWM) value to control the heater [21]-[23]. This PWM value is sent to the heater driver, which regulates the power supplied to the heater so that the heater can increase the temperature as needed. Additionally, the Arduino controls the fan via the fan driver; the fan is activated or deactivated based on the measured temperature to assist in cooling if needed [24]. The system is connected to the IoT platform Thinger.io [25] via the ESP8266 module, enabling remote monitoring and control. Users can monitor temperature, humidity, setpoints, and other system statuses and adjust temperature setpoints through the Thinger.io interface. The system operates in a continuous loop where temperature is measured, control is calculated and applied, and data is sent to Thinger.io to ensure effective and efficient temperature control.

The temperature control system flowchart in Figure 3 can be explained as follows: first, the Arduino and sensor are initialized, where the Arduino sets the appropriate pins and ensures that the sensor is ready for use. Once the sensor is active and functioning properly, the temperature and humidity data measured by the sensor are sent to the Thinger.io platform. The Thinger.io server then receives the data from the sensor sent by the Arduino, processes it, and stores it on the server. The data sent from the Arduino, including temperature and weight values, is displayed on the Thinger.io dashboard. Next, the fuzzification process is performed, where the measured temperature values are converted into fuzzy values for further processing using fuzzy logic. This fuzzy control is used to regulate the heating system based on the set temperature. The fuzzified temperature values are then sent back to Thinger.io for further monitoring, allowing us to see how the temperature values are processed and regulated by the control system in real-time that described ini Figure 3.

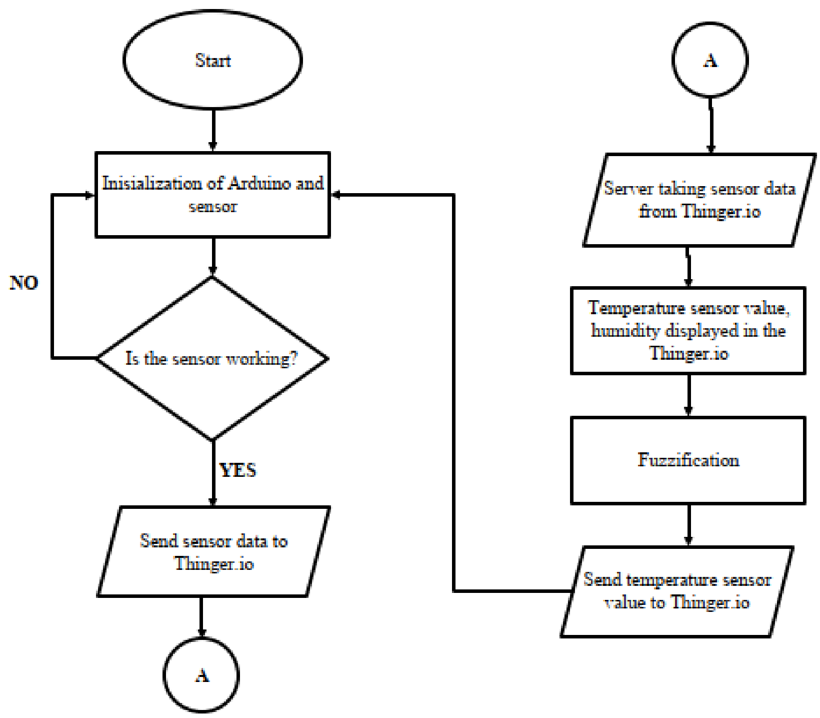

Figure 3. Flowchart of the system

3. RESULTS AND DISCUSSION

3.1. Incubator box design results

The incubator box device in Figure 4 consists of one heating element with specifications of 220 v/40 w and one fan with specifications of 12 V/0.15 A, which is placed on the right side of the incubator. The heating element and fan are aligned to allow hot air to be quickly distributed upward, and the angled placement of the fan is intended to ensure that hot air reaches the entire incubator. Each side of the incubator also has holes that serve as entry points for hot air from below.

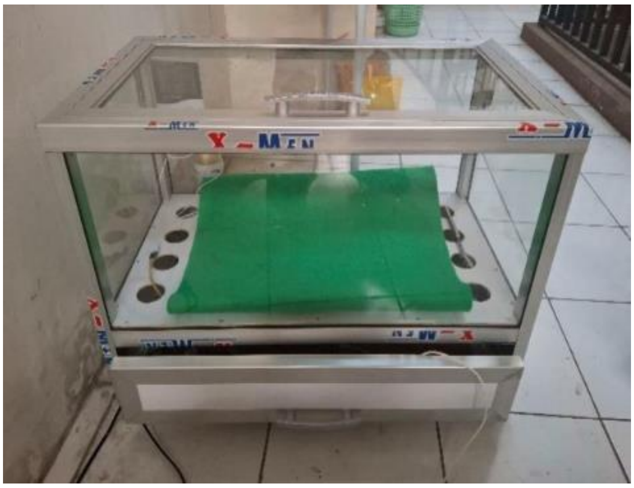

Figure 4. Incubator box construction

Based on the research conducted, the incubator device functions well overall. The single heating element and fan operate effectively and can distribute hot air from the bottom to the top through the angled placement of the fan. Based on the research conducted, the incubator device can be used effectively. The single heating element and fan function properly and can channel hot air from the bottom upward through the small holes inside the incubator.

3.2. Temperature control design results

In designing this temperature control system, we decided to use two power sources because the heater requires a current of approximately 5.5 A. For the heater to work optimally, a power supply with a minimum current of 5.5 A is required. Therefore, we used a 12 V/10 A power source specifically for the heater. This power supply is not connected to other components to avoid issues with the GND path and other components.

The other power supply, which has been reduced to 5 V and 1 A, is used to power the fan relay. Since connecting the Arduino R3 built-in Wi-Fi board ESP8266 board with an internet connection requires a current of 300 mA, while the current provided by the board is only 500 mA. However, the GND placement of the fan relay is on the same line as the Arduino's GND.

Based on Figure 5, we can see several components, including:

1) Arduino R3 built-in Wi-Fi ESP8266
2) This Arduino is a type of board that can switch modes without having to use two boards at once. By simply changing the switch on the board, we can immediately switch modes from Arduino UNO to ESP8266.
3) 12 V/10 A power supply
4) This power supply is used to provide input power specifically for the relay that will be connected to control the heater.
5) Breadboard
6) The breadboard is where all types of wiring are connected, including VCC(+), GND(-), and data pins.
7) 12 V/3 A power supply
8) This power supply is intended to supply current to other components.
9) Relay
10) In my component design, we use two relays. Each relay has VCC, GND, and data pins, which are connected via the breadboard to the (+), (-), and data pins of the Arduino. The relays also have NO and COM terminals, where COM is the power source from the power supply and NO is the VCC for the heater or fan.
11) Fan
12) 5 V/1 A step-down converter

This device is used to reduce the voltage and current input from the power supply to 5 V. This is done so that the resulting voltage can be used as input for the Arduino board, preventing the board from experiencing overvoltage that could damage its electronic components.

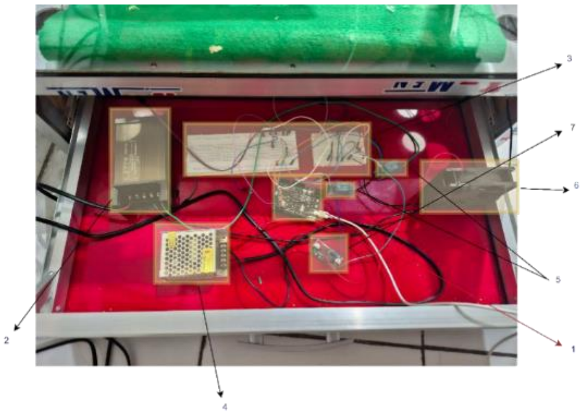

Figure 5. Temperature control design

3.3. IoT dashboard design results

To enable real-time monitoring of incubator temperature, we chose Thinger.io as the primary platform. Thinger.io has a very helpful dashboard feature that allows us to set up and customize the temperature monitoring graph display according to our needs. This feature is very important because it allows us to view. This feature is crucial because it allows us to view temperature data from the sensors installed in the incubator more easily and intuitively. With this dashboard, we can monitor temperature in real-time, make faster and more accurate decisions based on precise data, and enhance efficiency in managing incubator temperature. Figure 6 presents the Thinger.io dashboard used for real-time temperature monitoring and remote control of the system, including setpoint adjustment and on/off operation.

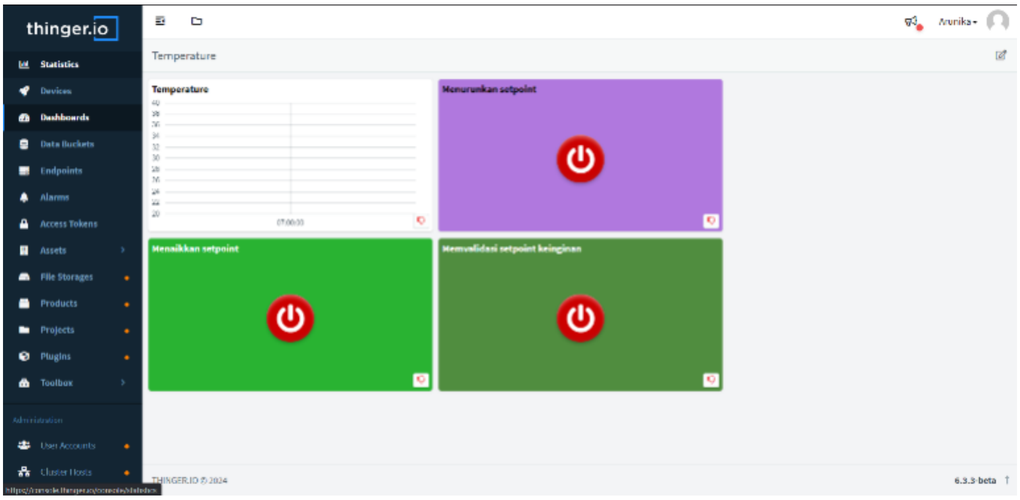

Figure 6. Thinger.io dashboard display

3.4. Test performance

After the incubator box was completed and the fuzzy control system was implemented, we were able to monitor the sensor readings through the IoT platform. Next, we conducted two tests to ensure that the system was functioning properly.

3.4.1. Temperature sensor test using thermometer

This test aims to ensure that the DHT22 sensor used in the incubator control system does not have significant differences. The test is conducted under controlled conditions to ensure the data obtained is valid. By using a standard thermometer as a scientifically recognized reference measurement tool, it can be seen how well the temperature sensor performs under various temperature conditions inside the incubator. The sensor readings will be monitored through Thinger.io.

From the Table 1, we can find the error value of the sensor using (1).

$$\%Error = \left|\frac{x}{xi}\right| x100\%$$
$$\%Error = \left|\frac{29.4}{30.1}\right| x100\% = 0.97\% \quad (1)$$

From the error analysis conducted, it was revealed that the DHT22 sensor has a minimal error rate of 0.97%. This indicates that the temperature measurements taken by the DHT22 sensor inside the incubator show significant consistency with the actual temperature conditions inside the incubator.

Table 1. Temperature comparison between thermometer and sensor

Time (minutes)	DHT22 sensor temperature (℃)	Thermometer temperature (℃)
2	30.1	29.4
4	30.2	29.5
6	30.3	29.6
8	30.3	29.7
10	30.4	29.7

3.4.2. Testing the body temperature of mice

After the temperature control test yielded satisfactory results, at this stage, the body temperature of mice will be assessed. This assessment aims to replace the position of babies in the study, as the morphology of mice is almost similar to that of humans. The test will last for 2 hours, with temperature monitoring conducted every 20 minutes. The test will last for 2 hours, with temperature monitoring conducted every 20 minutes. Based on the Table 2, we can see that the body temperature of the mice rose gradually in accordance with the conditions inside the incubator box. With these results, the setpoint of the previously set temperature sensor was achieved. Around the 90^{th} minute, the body temperature of the mice no longer increases because the setpoint of the temperature sensor has been reached, and the heating control system (heater) of the incubator automatically shuts off.

Table 2. Mice temperature every 20 minutes

Time (minutes)	DHT22 sensor Temperature (℃)
0	35.8
20	35.9
40	36.0
60	36.1
80	36.2
100	36.2
120	36.2

4. CONCLUSION

This study successfully designed and built an IoT-based baby incubator simulator using Arduino UNO. The system focuses on controlling the temperature and humidity in the baby incubator, with integrated sensors providing real-time feedback to ensure optimal conditions. IoT connectivity enables remote monitoring and control, greatly facilitating the understanding and management of temperature and humidity for the care of premature infants. Test results show that the temperature sensors used are highly accurate, with minimal error rates, thereby providing measurements that align with actual conditions inside the incubator. Body temperature testing on mice also yielded good results, with mouse body temperature gradually increasing in line with conditions inside the incubator box. By the 90^{th} minute, mouse body temperature reached the setpoint of the temperature sensor, indicating that the incubator's heating control system is functioning properly.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Liza Rusdiyana	✓	✓		✓	✓	✓		✓	✓	✓		✓		✓
Joel Juanda Jamot Damanik		✓	✓			✓		✓	✓		✓		✓	
Bambang Sampurno	✓			✓				✓				✓		
Suhariyanto		✓		✓						✓		✓		
Mahirul Mursid				✓					✓	✓			✓	
Ika Silviana Widianti			✓	✓			✓		✓	✓	✓		✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The author confirms that there are no conflicts of interest to declare.

INFORMED CONSENT

All procedures involving animals were conducted in accordance with applicable national regulations and institutional guidelines for their care and use.

ETHICAL APPROVAL

Informed consent was obtained from all participants involved in this research.

DATA AVAILABILITY

Data supporting the conclusions of this study can be provided by the corresponding author upon reasonable request. However, any data that might reveal participants' identities or sensitive information are not publicly accessible due to privacy considerations.

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