IoT-enhanced infant incubator monitoring system with 1D-CNN temperature prediction model

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ABSTRACT

This research aims to develop a monitoring system and temperature prediction model in neonatal premature infant incubators by applying the internet of things (IoT) concept and the 1-dimensional convolutional neural network (1D-CNN) method. The system is designed by integrating sensors, actuators, and microcontrollers connected through Wi-Fi network with message queue telemetry transport (MQTT) protocol. Sensor data in the incubator is stored in a database and displayed in real-time on a web application. The data in the database is also used for creating a temperature prediction model in the incubator. Test results indicate that the best model configuration consists of 5 neurons in the first layer, 20 neurons in the second layer, and a dense layer with 100. The evaluation of this model yields a high level of accuracy with an root mean square error (RMSE) of 0.200 °C, MSE of 0.004 °C, mean absolute error (MAE) of 0.152 °C, and mean absolute percentage error (MAPE) of 0.4%. Based on the error values obtained between the predicted and actual values from each evaluation technique in the model, it can be concluded that the range between the real and predicted values is approximately 0.2 °C. Overall, this research contributes to improving the quality of care for premature infants.

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1. INTRODUCTION

Babies born before reaching 37 weeks of gestation often face serious health issues. Such births are referred to as premature births. Premature babies require intensive care in the neonatal intensive care unit (NICU) at hospitals [1], [2]. One crucial factor in the care of premature infants is maintaining their body temperature within an optimal range as per medical standards. To support the care of premature babies, an essential device known as an incubator is required.

An incubator is a highly essential device for maintaining the condition of babies and preventing hypothermia or hyperthermia. Monitoring and controlling the temperature within the incubator must be carried out meticulously and require specialized knowledge in premature infant care. Therefore, medical personnel must be readily available in the NICU to continuously monitor the temperature conditions inside the incubator. As a result, in this research, we have developed a monitoring system and temperature prediction model for incubators to enhance the care of premature babies. We have achieved this by applying the concepts of the internet of things (IoT) [3], [4] and artificial intelligence, using the 1-dimensional convolutional neural network (1D-CNN) method [5].

Research on incubator control systems has been conducted previously. Previous studies have focused more on control systems using proportional integral derivative (PID) and fuzzy. Additionally, for monitoring systems, message queue telemetry transport (MQTT) protocol with a third-party IoT broker has been used, where the provided features are still limited. In previous research, the focus was on using fuzzy and PID algorithms to control the system to maintain temperature as desired [6], [7]. However, some studies only concentrated on monitoring temperature and humidity without any systematic control. In the monitoring process, the use of an IoT broker from Node-RED platform, a third-party provider, may imply potential insecurity of patient data or limitations in using its features [8], [9]. Based on the conducted research, we have developed a predictive system for future temperature conditions in an incubator by integrating IoT and artificial intelligence. This predictive system aims to provide early warnings in case of any issues with the baby. The system can predict temperature conditions using convolutional neural network (CNN) methods [10]. Meanwhile, the monitoring system utilizes the MQTT protocol with an IoT broker installed on a mini-computer. Additionally, there is also a database system to store temperature data, which can be displayed in real-time on a web page.

The IoT is a concept that enables objects or hardware devices to communicate with each other without human intervention [11]-[13]. Therefore, implementing IoT in an incubator can be achieved by utilizing sensors, actuators, and microcontrollers connected to the internet. This allows the incubator to be accessed from anywhere and at any time to monitor temperature conditions in real-time.

The development of the IoT-based system utilizes hardware, namely the NodeMCU-12E microcontroller board, equipped with a Wi-Fi module to support communication [14], [15]. The NodeMCU-12E board functions as a controller for temperature sensors and actuators [16]. For the temperature sensor, the system employs the DHT22 module, capable of accurately measuring both temperature and humidity with a humidity accuracy level of 2-5% relative humidity (RH) and temperature accuracy of less than 0.5 ºC [17], [18]. Additionally, relay actuators are used to control the on-off status of the heater and blower devices. The blower's role is to circulate hot air into the incubator.

Furthermore, the communication process between the incubator and the software or application is conducted over Wi-Fi networks, leveraging the MQTT communication protocol [19]. MQTT is a lightweight communication protocol designed to transmit data between devices connected to TCP/IP-based networks. In the communication process, MQTT protocol requires an IoT broker that acts as an intermediary for data exchange among various objects, software, and databases. The terms used for communication in MQTT are publish (pub) and subscribe (sub) [20]. In this research, we employ the Eclipse Mosquitto IoT broker installed on a Raspberry Pi mini-computer board [21].

In software development, we have created a web-based application [22]. The developed web application features a responsive user interface, making it easily accessible on various screen sizes. The web interface is designed to display sensor data stored in the database in real-time, presented in the form of graphs and tables. This user-friendly interface greatly aids medical personnel in monitoring the incubator's condition, allowing for easy access and data visualization.

Additionally, the data stored in the database is analyzed to create a model capable of predicting future incubator temperature conditions. This analytical process involves deep learning using the 1D-CNN method, which is a type of CNN specifically designed for processing one-dimensional or sequential data [23], [24]. By using 1D-CNN, it can extract important temporal patterns from the accumulated temperature data over time inside the incubator. Thus, the model developed using this method can learn from these patterns and generate more accurate temperature predictions for the future. This enables taking necessary actions promptly if significant temperature changes occur within the incubator.

In the initial step of model creation, the sensor data stored in the database is extracted to form a dataset. This dataset is then processed to generate a new dataset, which is subsequently used in model development. Next, this new dataset is divided into two parts: the training data and the testing data. In the following phase, the training data is employed to develop the model, and the model's results are evaluated to determine accuracy levels based on testing outcomes.

Finally, the results of this research have yielded several outputs, namely a web application, a device prototype, and a predictive model for temperature. The web application is used to monitor incubator conditions in real-time, accessible from anywhere and at any time via the internet. The device prototype is an electronic incubator consisting of sensors, actuators, and a microcontroller. Meanwhile, the model is used to generate temperature predictions for the future.

2. RELATED WORKS

The previous research on incubators served as a reference for the development of this study. Irianto *et al.* in 2023 [7] focused on monitoring and controlling the temperature and heart rate of premature babies using IoT and PID control for temperature regulation. Furthermore, Alimuddin *et al.* [6] worked on developing a system for monitoring and controlling temperature and humidity in an incubator using a hybrid fuzzy-PID method. Aya-Parra *et al.* [8] investigated a baby incubator monitoring system using IoT. The sensors used included temperature, humidity, and sound. They employed Wi-Fi and MQTT protocol for networking and utilized NodeRED services. Sukma *et al.* [9] conducted research on monitoring temperature in a baby incubator. Wi-Fi was used for communication, along with the MQTT communication protocol. This study also analyzed the quality of service (QoS) of the MQTT protocol. In addition, in 2023, we also conducted research on baby incubators to monitor electricity usage and created a predictive model for electricity consumption using long short-term memory LSTM and 1D-CNN methods [25].

In our research, we focused on monitoring temperature and humidity conditions using the IoT concept and developing a temperature prediction model using the CNN method. This study combines the IoT with artificial intelligence to enhance the care of premature infants. The communication between devices in the system is facilitated by Wi-Fi and the MQTT communication protocol, with the assistance of the IoT Broker Eclipse Mosquitto. The system developed also incorporates a MySQL database [26] and both web and mobile application interfaces. A comprehensive comparison between the present study and previous research can be observed in Table 1.

Table 1. Summary of related works on neonatal incubators

Reference	Sensor	Network	Protocol	IoT broker	Database	Application	Method
[27]	Temperature, humidity	Wi-Fi	-	-	-	-	-
[6]	Temperature, humidity	-	-	-	-	Desktop	Fuzzy-PID
[7]	Temperature; heartrate	Wi-Fi	-	Firebase	-	Mobile	PID
[8]	Temperature, humidity, sound	Wi-Fi	MQTT	Node-RED	MySQL	web	-
[9]	Temperature	Wi-Fi	MQTT	Node-RED	-	Web	-
Our works	Temperature, humidity	Wi-Fi	MQTT; HTTP	Eclipse Mosquitto	MySQL	Web; mobile	1D-CNN

3. MATERIALS AND METHOD

3.1. System overview

In Figure 1, the general system design for the development of monitoring and temperature prediction model in the incubator is illustrated. The overall design begins with the hardware components of the incubator, including sensors, actuators, and microcontrollers responsible for reading sensor data. This sensor data is subsequently transmitted to the IoT broker via a Wi-Fi network, utilizing the MQTT protocol [28].

Within the IoT broker, all data sent by the incubator is processed based on the topics associated with each data or object. Subsequently, this data is transmitted to the database using the MQTT protocol according to the subscribed data. The communication process between the IoT broker and the database utilizes socket services through the MQTT protocol.

Once the data is stored in the database, it undergoes analysis. The analysis process is divided into two stages: firstly, the data is processed for presentation in the web application, and secondly, it is analyzed to construct a predictive model for the incubator's temperature conditions. To obtain data for presentation in the web application, the use of an application programming interface (API) is employed [29]. The API serves as a system that acts as a bridge between the application and the database.

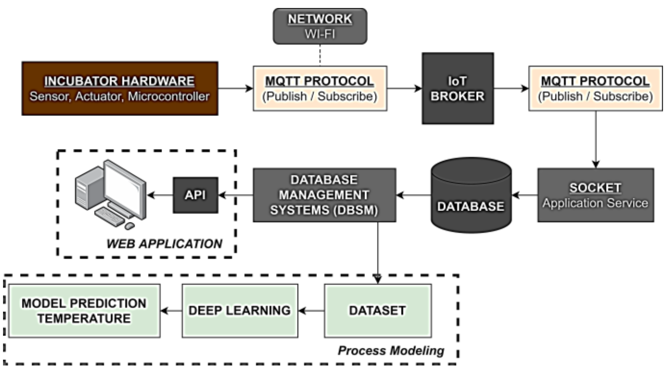


Figure 1. System overview

Subsequently, in the model analysis process, the data in the database is transformed into a dataset. This dataset comprises several features, including temperature and humidity sensor data, totaling eight features. These eight features are derived from four sensors, each providing two features, resulting in a total of eight. The dataset is then processed using the 1D-CNN method, as the data used is sequential in nature [30]. The outcome of this analysis yields a model that can be utilized for temperature prediction.

3.2. Hardware design

In Figure 2, the hardware design for monitoring temperature and humidity in the incubator is depicted. The primary device utilized for this purpose is the NodeMCU-12E microcontroller board [31]. This board features a 2.4 GHz Wi-Fi module and employs the ESP-8266 32-bit microcontroller with 11 digital input/output (I/O) pins and 1 analog I/O pin [32], [33]. Additionally, the board operates at a voltage of 3.3 V for the sensors and actuators.

The actuator device used is a relay with two channels. This relay module is connected to the microcontroller board through digital I/O pins. The relay is further linked to the heater and blower fan devices within the incubator. The purpose of the relay is to control the on-off state of the heater and blower fan in the incubator.

Next, the DHT22 sensor module is employed to measure temperature and humidity inside the incubator [34]. In this study, four sensors are used and positioned at each corner of the incubator, as illustrated in Figure 3. This arrangement of sensors is designed to ensure even temperature distribution within the incubator. The schematic of the DHT22 sensor is connected to the microcontroller board through I/O pins. The specifications of the DHT22 sensor encompass a temperature measurement range from -40 °C to 80 °C and humidity measurement range from 0% to 100% RH [18].

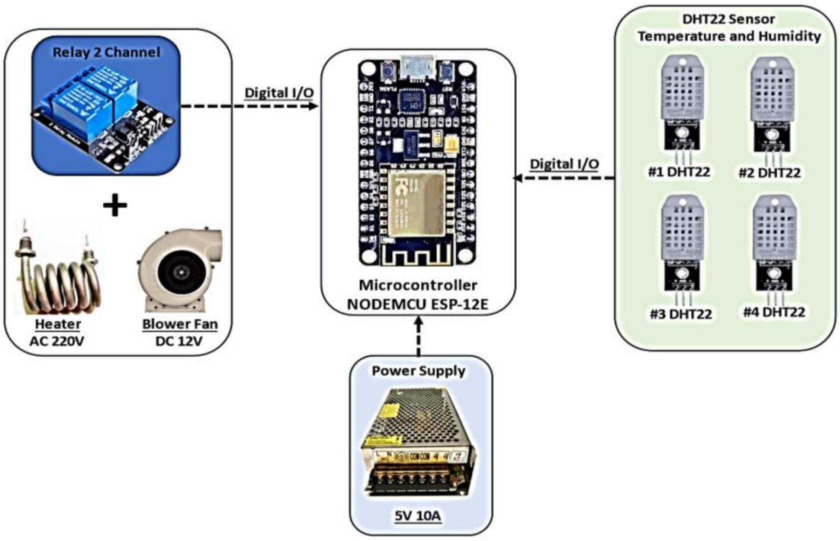


Figure 2. Hardware design

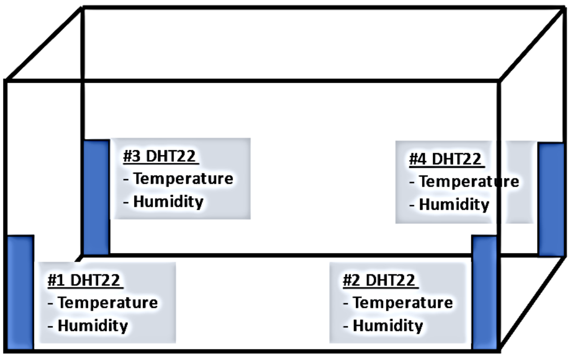


Figure 3. Position sensor

3.3. Software design

The software design for monitoring through the web application can be observed in Figure 4. The initial step begins when a medical staff (user) accesses the web application, at which point the system will display the login page. On the login page, there is a form to input the user's username and password. Subsequently, the system performs an authentication process to verify the entered username and password. If the entered data is correct or valid, the system will respond by displaying the dashboard page. On the dashboard page, sensor data regarding the incubator's condition is presented in the form of graphs and tables.

The data displayed on the dashboard page is obtained in real-time from the database. This is achieved through a process where the client (web application) sends periodic data requests to the server at one-second intervals using the hypertext transfer protocol (HTTP) protocol [35]. Subsequently, the data requests are processed by the web server or API to retrieve the data from the database. The resulting data from the database or server response is then transmitted to the client in JSON format [36]. Afterward, this JSON-formatted data is converted into graphical and tabular formats to be displayed on the web dashboard page.

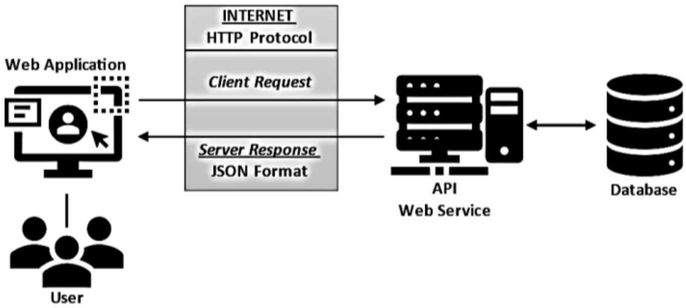


Figure 4. Software design

3.4. Network design

Figure 5 illustrates the network configuration design used to facilitate communication between various components within the incubator and the software. The communication process is based on the MQTT protocol, which involves the concepts of publish and subscribe, which can be equated to communication terminology such as transmit (TX) and receive (RX). This protocol is specifically designed to overcome communication challenges in environments with network and power constraints, such as those commonly encountered in IoT devices and sensors [37].

In order to use the MQTT protocol, an IoT Broker is required. In our research, we utilized the Eclipse Mosquitto Broker application [38], which we installed on a Raspberry Pi mini-computer [39]. Configuration processes are essential for the IoT broker, such as specifying Host, Port, ID, username, and password. subsequently, each object or sensor within the incubator needs to be aligned with the configuration settings of the IoT broker to ensure seamless connectivity. Data transmitted to the IoT broker is processed and then stored in the database using socket services. We implemented the Socket service in the Python programming language with the Eclipse Paho library, configuring it to facilitate communication between the broker and the database. The socket service operates by continuously looping to process data from the broker and store it in the database.

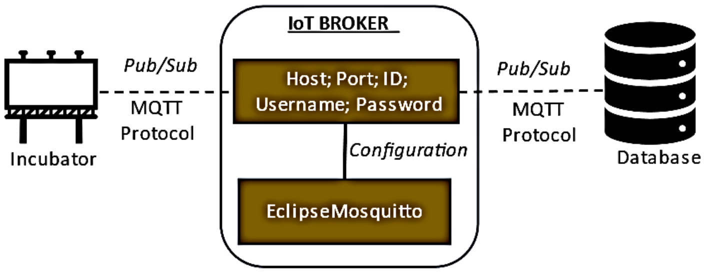


Figure 5. Network design

3.5. Data management

Data management is achieved by storing information within a database. The structure for sensor data storage in the database is outlined in Table 2. The data from the DHT22 devices comprise two main types: temperature and humidity [40]. In our research, we employed 4 DHT22 sensors, which resulted in a total of 8 data points encompassing both temperature and humidity. These data points are numerical in nature, so the chosen data type is float. This data type accommodates fractional values, which align with the sensor-generated data, such as temperature values like 32.50 and humidity values like 45.90. Additionally, time data is captured using the realtime clock (RTC) DS1302 device [41], yielding date and time values. For time data, the specified data type is timestamp, formatted as yyyy-mm-dd hh:mm:ss.

Table 2. Sensor data description in database

Device	Data variable	Example value	Unit	Data type
DHT22	Temperature	32.50	℃	Float
DHT22	Humidity	45.90	%	Float
RTC	Datetime	2023-07-21 10:00:00	yyyy-mm-dd hh:mm:ss	Timestamp

Based on the data stored in the database, we exported and processed it to create a dataset. The resulting dataset comprises 9 attributes, including temperature and humidity data from 4 sensors. The attribute names in the dataset are as follows; temp_1, temp_2, temp_3, temp_4, humi_1, humi_2, humi_3, humi_4, and t_target. The t_target attribute represents the average value of data from temp_1, temp_2, temp_3, and temp_4. In this research, the t_target attribute will be used as the label. A detailed description of the dataset is provided in Table 3. To calculate the correlation between each attribute in the dataset, formula 1 is used [42].

Table 3. Dataset attribute

Attribute	Unit	Descriptions	Attribute	Unit	Descriptions
Temp_1	℃	Temperature sensor 1	Humi_1	%	Humidity sensor 1
Temp_2	℃	Temperature sensor 2	Humi_2	%	Humidity sensor 2
Temp_3	℃	Temperature sensor 3	Humi_3	%	Humidity sensor 3
Temp_4	℃	Temperature sensor 4	Humi_4	%	Humidity sensor 4
			T_target	℃	Temperature

$$r = \frac{n\sum_{i=1}^{n} x_i\, y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2}\ \sqrt{n\sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2}} \tag{1}$$

3.6. Convolutional neural network

In this study, the 1D-CNN method is employed for temperature prediction. This method is a type of artificial neural network designed to process time series data or one-dimensional data [43], [44]. Hence, we use 1D-CNN to analyze sensor data in the incubator to understand temperature variations. The mathematical explanation for 1D-CNN is shown in formula 2 [45].

Furthermore, let's explain the architectural design of the model-building process. The initial step begins with dataset collection, which consists of 9 attributes as input. Next, the core modeling process occurs in the convolutional layer. Following that, the flattening process takes place, and then it proceeds to the dense layer, ultimately producing the output. For a detailed design of the modeling architecture using 1D-CNN, refer to Figure 6 [46]. In Table 4 presents details regarding the parameters or characteristics of each layer.

$$c(n) = f\left(\sum_{i=-l}^{l} \omega(i) \cdot x(n-i) + b\right) \tag{2}$$

3.7. Evaluation model

Following model creation, the next step is the evaluation process to measure the model's accuracy. This evaluation process employs the root mean square error (RMSE), mean absolute error (MAE), mean squared error (MSE), and mean absolute percentage error (MAPE) techniques. The mathematical calculations for each evaluation technique, such as RMSE, MAE, MSE, and MAPE, can be seen in Formulas 3 to 6 [46]-[48].

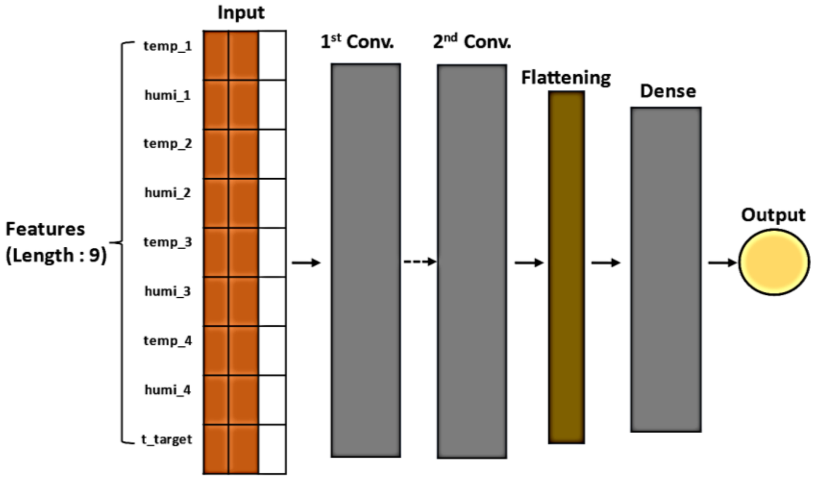


Figure 6. CNN model architecture

Table 4. 1D-CNN characteristics of the proposed model

Layer	Characteristics
1st Convolutional	Filter = 5; Kernel Size = 3; activation = ReLu
2nd Convolutional	Filter = 20; Kernel Size = a; Activation = ReLu
Flattening	-
Dense	Unit = 10a; Activation = ReLu

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \tilde{y_i})^2}{n}} \quad (3)$$

$$MAE = \frac{\sum_{i=1}^{n}|y_i - \tilde{y_i}|}{n} \quad (4)$$

$$MSE = \frac{\sum_{i=1}^{n}|y(i) - \tilde{y}_i|^2}{n} \quad (5)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|y_i - \tilde{y_i}|}{y_i} \times 100\% \quad (6)$$

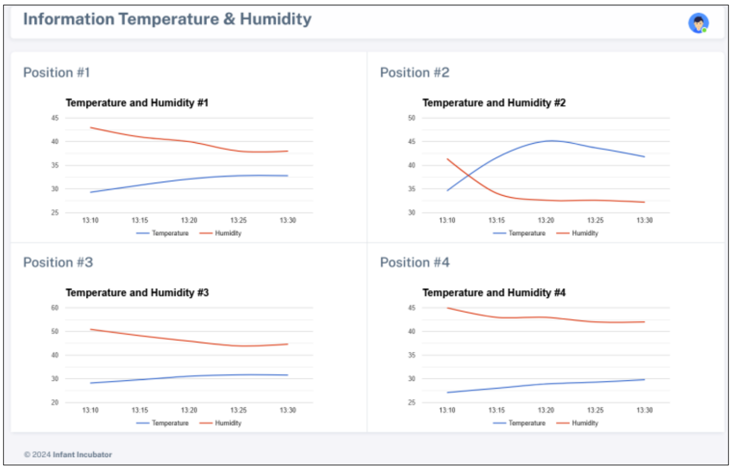
4. RESULTS AND DISCUSSION

This section describes the implementation results divided into several parts, including the web application, hardware prototype, data, and temperature prediction model. For the web application results, can see them in Figure 7. On the dashboard page of the web application, as shown in Figure 7(a), it displays temperature and humidity data in the form of graphs. The data displayed is based on the sensor positions, which range from 1 to 4, and are differentiated in separate panels. Each panel on the dashboard page contains graphs that display temperature sensor data (blue line) and humidity sensor data (red line) for each position or corner of the incubator. Subsequently, in Figure 7(b), it displays the web page for presenting temperature and humidity data for all sensor positions in a tabular format.

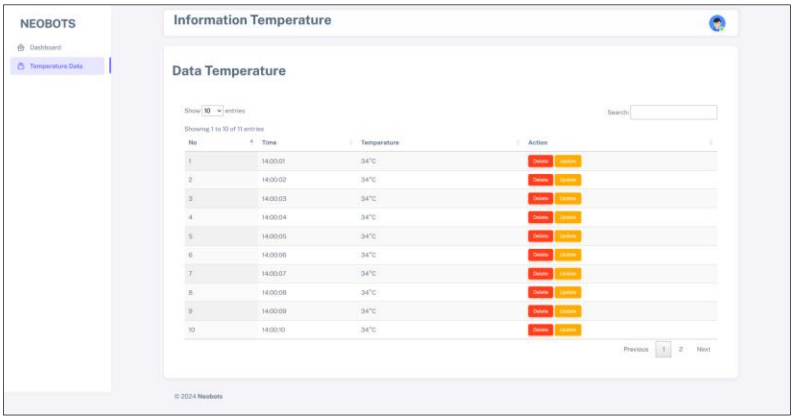
Next, the prototype results of the incubator can be seen in Figure 8. This prototype is divided into two parts: the infant incubator box equipped with sensors mounted on each side, as shown in Figure 8(a). The electronic implementation results can be seen in Figure 8(b). The components in this electronic prototype consist of the NodeMCU-12E microcontroller board module, connected to relays to control the on-off state of the heater and other components.

Then, the data stored in the database is converted into a dataset. The data patterns within the dataset are visualized, as shown in Figure 9. It appears that we found different data patterns for each sensor in the corners of the incubator, as seen in Figures 9(a) to 9(d). This indicates that the temperature and humidity conditions are not uniform in each corner. The temperature and humidity conditions recorded by these sensors suggest that the airflow inside the incubator is suboptimal, which is the cause.

Furthermore, we obtained the average temperature values within the incubator, which are used as the target or label in the dataset. The visual data patterns can be observed in Figure 9(e). Additionally, we calculated the coefficient of correlation (*r*) for each attribute in the dataset, which is presented comprehensively in Table 5. The correlation coefficient for the target attribute is 0.57 with the attribute temp_3, 0.52 with the attribute temp_2, and 0.17 with the attribute temp_1, indicating a positive relationship between the target attribute and temp_3, temp_2, and temp_1.

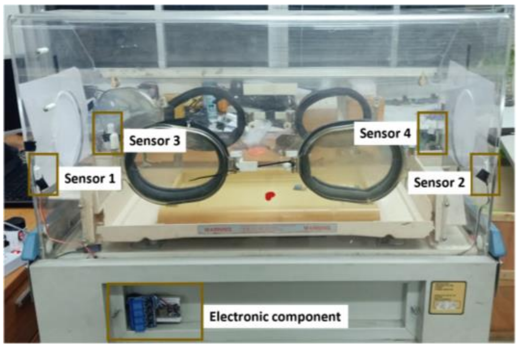


(a)

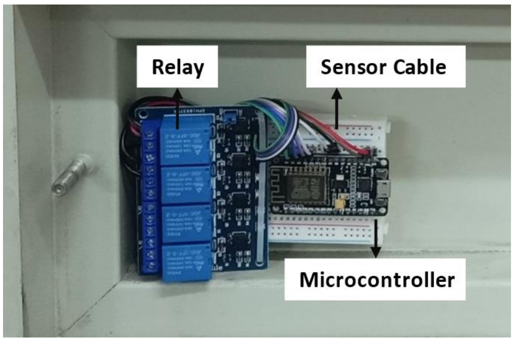


(b)

Figure 7. Web application (a) dashboard page and (b) record data page

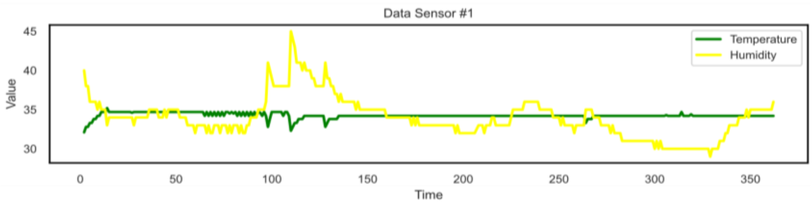


(a)

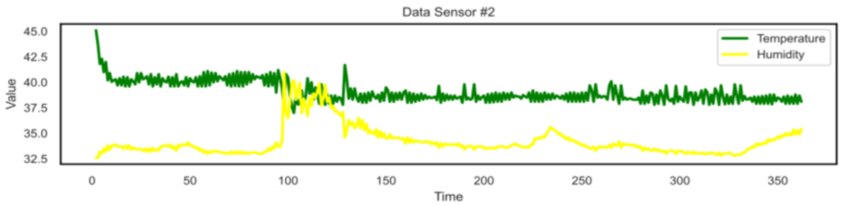


(b)

Figure 8. Hardware prototype (a) infant incubator and (b) electronic component



(a)



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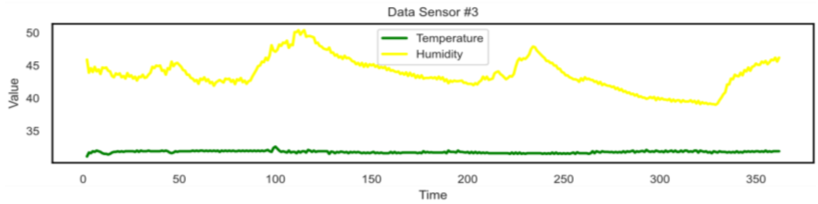
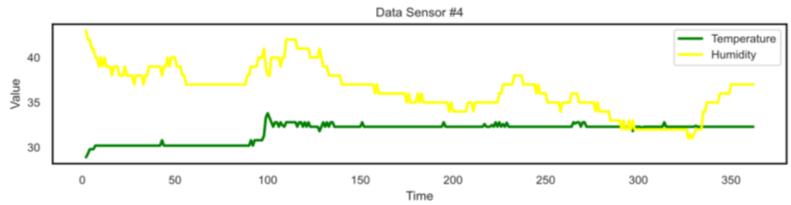
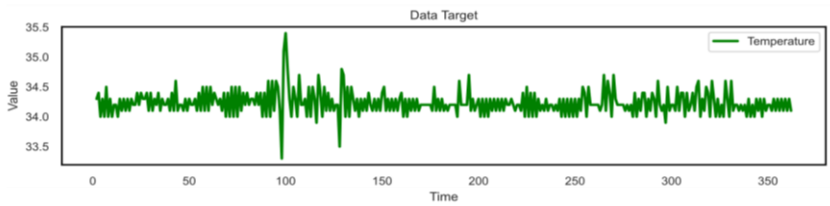


(c)



(d)



(e)

Figure 9. Information value of the dataset; (a) data attributes temp_1 and humi_1, (b) data attributes temp_2 and humi_2, (c) data attributes temp_3 and humi_3, (d) data attributes temp_4 and humi_4, and (e) data attribute t_target

Subsequently, the results of creating a temperature prediction model using the 1D-CNN method are presented in Table 6. The best test results were obtained with Neurons-1 at 5 and Neurons-2 at 20, with a Dense value of 100, resulting in an RMSE of 0.200 °C, MSE of 0.004 °C, MAE of 0.152 °C, and MAPE of 0.4%. The results show an RMSE of 0.202 °C, MSE of 0.005 °C, MAE of 0.168 °C, and MAPE of 0.5% for the model with Neurons-1 at 45 and Neurons-2 at 20 with Dense value of 100. Additionally, the model with Neurons-1 at 5 and Neurons-2 at 10 with Dense 80 yielded RMSE of 0.205 °C, MSE of 0.005 °C, MAE of 0.161°C, and MAPE of 0.5%. Furthermore, the model with Neurons-1 set to 20 and Neurons-2 set to 20 with Dense 100 resulted in RMSE of 0.209 °C, MSE of 0.005 ˚C, MAE of 0.166 °C, and MAPE of 0.5%.

Furthermore, the visualization of the prediction results of the best model can be seen in Figure 10. In this figure, it can be observed that four models have an error value in predicting the temperature of less than 0.210 °C. The results of these models can be seen in each respective figure as follows. Figure 10(a) represents the outcomes for the parameters Neurons-1 set to 5, Neurons-2 set to 20, and Dense set to 100. Figure 10(b) illustrates the results for the parameters Neurons-1 set to 45, Neurons-2 set to 20, and Dense set to 100. Figure 10(c) depicts the results for the parameters Neurons-1 set to 5, Neurons-2 set to 10, and Dense set to 80. Lastly, Figure 10(d) shows the results for the parameters Neurons-1 set to 20, Neurons-2 set to 20, and Dense set to 100. In these graphs, a comparison is made between the prediction results (red line) and the actual data (blue line).

Table 5. Correlation coefficient of attribute in the dataset

	Temp_1	Humi_1	Temp_2	Humi_2	Temp_3	Humi_3	Temp_4	Humi_4	T_target
Temp_1	1	-0.36	0.073	-0.24	0.32	-0.18	-0.35	-0.073	0.17
Humi_1	-0.36	1	0.13	0.8	-0.052	0.93	0.047	0.85	0.053
Temp_2	0.073	0.13	1	-0.33	0.37	0.032	-0.73	0.42	0.52
Humi_2	-0.24	0.8	-0.33	1	-0.022	0.8	0.38	0.57	-0.083
Temp_3	0.32	-0.052	0.37	-0.022	1	-0.1	-0.22	0.048	0.57
Humi_3	-0.18	0.93	0.032	0.8	-0.1	1	0.063	0.85	0.014
Temp_4	-0.35	0.047	-0.73	0.38	-0.22	0.063	1	-0.4	0.074
Humi_4	-0.073	0.86	0.42	0.56	0.048	0.85	-0.4	1	0.029
T_target	0.17	0.053	0.52	-0.083	0.57	0.014	0.074	0.029	1

Table 6. The result of the 1D-CNN testing

Neurons 1	Neurons 2	Dense	RMSE (ºC)	MSE (ºC)	MAE (ºC)	MAPE (%)
5	10	80	0.205	0.005	0.161	0.5
10	10	80	0.215	0.005	0.169	0.5
15	10	80	0.254	0.006	0.191	0.6
20	10	80	0.225	0.005	0.170	0.5
25	10	80	0.421	0.009	0.312	0.9
30	10	80	0.341	0.008	0.273	0.8
35	10	80	0.379	0.009	0.305	0.9
40	10	80	0.309	0.007	0.254	0.7
45	10	80	0.452	0.011	0.374	0.11
50	10	80	0.341	0.008	0.269	0.8
5	20	100	0.200	0.004	0.152	0.4
10	20	100	0.531	0.013	0.434	0.13
15	20	100	0.227	0.005	0.177	0.5
20	20	100	0.209	0.005	0.166	0.5
25	20	100	0.326	0.007	0.254	0.7
30	20	100	0.321	0.008	0.257	0.8
35	20	100	0.303	0.007	0.234	0.7
40	20	100	0.268	0.006	0.211	0.6
45	20	100	0.202	0.005	0.168	0.5
50	20	100	0.290	0.007	0.233	0.7

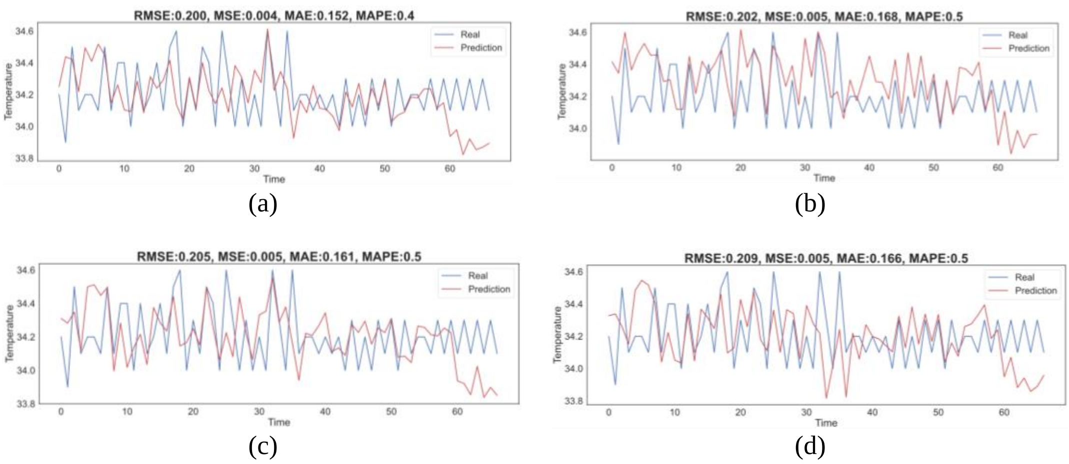


Figure 10. Results of temperature model prediction; (a) neurons-1: 5 and neurons-2: 20 with dense 100, (b) neurons-1: 45 and neurons-2: 20 with dense 100, (c) neurons-1: 5 and neurons-2: 10 with dense 80, and (d) neurons-1: 20 and neurons-2: 20 with dense 100

In this section, we also compare the research results using 1D-CNN with other methods such as LSTM, gated recurrent unit (GRU), and artificial neural networks (ANN). Based on the evaluation results shown in Table 7 for each of these methods, it is evident that the 1D-CNN method has smaller error values compared to the other three methods. This is evident from the RMSE values of LSTM being 0.286 ˚C, GRU being 1.089 °C, and ANN being 0.334 °C, while the last row shows the RMSE value of 1D-CNN as 0.200 ˚C.

Table 7. Compares 1D-CNN with other methods

Methods	RMSE (ºC)	MSE (ºC)	MAE (ºC)	MAPE (%)
LSTM	0.286	0.006	0.207	0.6
GRU	1.089	0.021	0.727	2.1
ANN	0.334	0.006	0.212	0.6
1D-CNN	0.200	0.004	0.152	0.4

5. CONCLUSION

Based on research conducted on monitoring and developing temperature prediction models in neonatal incubators using the IoT concept and 1D-CNN method, as well as evaluation techniques such as RMSE, MSE, MAE and MAPE, it can be concluded that this research has produced several main results. The system has been successfully designed and implemented using hardware components such as sensors, actuators, microcontrollers, and web-based software. The system utilizes Wi-Fi network communication with the MQTT protocol. The test results indicate that the system can automatically store temperature data in a database and display it on a web page. This facilitates the temperature monitoring process within the premature infant incubator. The best temperature prediction model results were obtained by configuring the model with 5 neurons in the first layer, 20 neurons in the second layer, and a dense layer with 100 units. The evaluation resulted in an RMSE of 0.200 °C, MSE of 0.004 °C, MAE of 0.152 °C, and MAPE of 0.4%. Furthermore, based on tests conducted using other methods such as LSTM, GRU, and ANN, the 1D-CNN method for predicting temperature in the incubator shows a lower error value, specifically less than 0.200, while the other methods indicate error values greater than 0.200. For future research, optimization of the model can be conducted to enhance computational efficiency.

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