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Design of Incu Analyzer for IoT-Based Baby Incubator Calibration

Salsabilla Kusuma Maulani, Syaifudin, Anita Miftahul Maghfiroh, and Levana Forra Wakidi

Department of Electromedical Engineering, Poltekkes Kemenkes Surabaya, Surabaya, INDONESIA
Corresponding author: Levana Forra Wakidi (e-mail: levana@poltekkesdepkes-sby.ac.id).
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ABSTRACT An incubator analyzer, serving as a calibration tool, is utilized to measure diverse parameters such as temperature, mattress temperature, humidity, airflow, and noise in infant incubators. The present study focuses on the development of the Design Incubator Analyzer for IoT (Mattress Temperature and Humidity) with LCD and ThingSpeak display, specifically designed for calibrating baby incubators. The primary objective is to design and develop an Incubator Analyzer as a calibration device for assessing various parameters in infant incubators, encompassing temperature, mattress temperature, humidity, airflow, and noise. The design of this calibration device incorporates a Thermocouple Type-K sensor for baby incubator mattress temperature parameters, a DHT22 sensor for humidity parameters, and an ESP32 microcontroller. The ESP32 processes data from the Thermocouple Type-K and DHT22 sensors to generate values for mattress temperature (TM) and humidity (RH), which are then displayed on LCD and ThingSpeak displays. The device underwent rigorous testing against an established measuring device, the INCU II. In the study, the TM parameter or mattress temperature exhibited the smallest error of -0.0140% at 35°C and the largest error of 0.0584% at 36°C. Concerning the humidity parameter, the largest error was 0.0570% at 32°C, while the smallest error was 0.0207% at 35°C. Overall, the Incubator Analyzer Design for IoT-Based Baby Incubator Calibration device, or IoT-based Incubator Analyzer, demonstrates potential usability following the planning and execution phases, including a thorough review of existing literature. To enhance user experience during the calibration process, an IoT system was developed for data transmission over Wi-Fi, presenting results on the ThingSpeak platform in real-time.

INDEX TERMS Incubator Analyzer, Baby Incubator, ESP32, DHT22, Thermocouple Type-K

I. INTRODUCTION

Premature births are those that take place between the 20th and 37th week of pregnancy or when the fetus weighs less than 2,500 grams. The risk of morbidity and mortality increases with younger gestational ages, making it difficult to care for a baby who is born prematurely. The causes of preterm labor can be attributed to iatrogenic factors (20%), infection (30%), premature rupture of membranes during preterm (20-25%), and spontaneous preterm labor (20-25%)[1]. In a theoretical context, risk factors for preterm birth can be categorized into four distinct groups: iatrogenic factors, maternal factors, fetal factors, and behavioral factors. Iatrogenic factors pertain to medical health-related influences. Prematurity in the past, maternal age, maternal parity, placenta Previa, cervical abnormalities (cervical incompetence), hydroniums, intra-amniotic infection, hypertension, and trauma are only a few examples of maternal variables. Fetal factors include twin pregnancies (gamely), fetal death (IUFD), and birth defects (congenital abnormalities). Behavioral factors encompass behaviors such as maternal smoking and alcohol consumption during pregnancy[2].

According to the World Health Organization (WHO), premature babies are defined as live births occurring before 37 weeks of gestation[3]. Premature baby organs don't function like mature babies. Therefore, he has more difficulties living outside his mother's uterus, such as idiopathic respiratory distress syndrome, aspiration pneumonia, intraventricular hemorrhage, detrimental fibroplasia, and hyperbilirubinemia [4]. The shorter the gestation period, the less perfect the growth of organs in the body, with the result that complications occur more easily and the higher the death rate. In this connection, most perinatal deaths occur in premature infants[5]. According to world data, premature births reach 75-80% of all babies who die at the age of less than 28 days. Data from WHO (2020) shows a very alarming number of infant deaths, known as the two-thirds phenomenon[6][7]. First, the phenomenon of two-thirds of infant deaths at the age of 0-1 year occurs in the neonatal period (0-28 days old babies). Second, two-thirds of infant deaths occur during the neonatal period and occur on the first day (Comers. com)[8][9].

One of the important life support equipment in the care of premature babies is the baby incubator. A baby incubator, as defined by Regulation of the Minister of Health Number 118 of 2014, is a closed space where a baby is placed in a sterile, controlled environment to keep it warm. The working system of this incubator is to circulate heated air throughout the incubator room with a controlled temperature range between 30 ° C - 37 ° C, the circulating temperature is then abscised into the baby's body through tissue conduction and blood convection[10]. A baby incubator is specifically designed to protect premature or underweight newborns by creating a stable environment with a temperature similar to that of the womb, thus ensuring the baby's body temperature remains constant. Besides temperature regulation, it is also essential to carefully monitor and maintain the humidity levels within the baby incubator[11].

The baby incubator comprises a heating unit, a fan for circulating warmed air, a water container for humidity regulation, an oxygen control valve, and an access port for administering medical treatments(Presences no 118 of 2014) [12].

To check the parameters of the incubator, the device must be calibrated. As stated in Presences Number 54 of 2015 related to calibration, calibration as a practical process used to ascertain the accuracy of measuring instruments and the data associated with measuring materials[13]. Examining and correcting the accuracy of measuring devices through comparison with defined references is the process of calibration[14]. A device called the Incubator Analyser was created specifically to examine the environmental conditions and operational aspects of infant incubators. Temperature, humidity, airflow, and noise levels are just a few of the many parameters the device can record and save. The feasibility of a baby incubator tool can be determined by the incubator analyzer tool[15].

Conducting regular tests and controls is crucial to ensure the accuracy of the baby incubator, as they play a significant role in reducing the likelihood of inadequate or erroneous measurements, thereby ensuring its reliability. The infant's safety may be at risk from inaccurate readings of the mattress's temperature and humidity levels in the baby incubator[16].

Drawing upon the findings of the literature search, the study employed the System Development Life Cycle (SDLC) approach, encompassing various stages such as planning, needs analysis, design, implementation, trials, and analysis of design outcomes. By using this method, the percentage of temperature readings has the highest error of 0.82%, which means it has an accuracy level of 99.18%, and the uncertainty value is ±0.015101°C. As for the moisture reading, the uncertainty value is ±0.134326%RH. With these results, it can be said that the parameters work with high accuracy and accuracy. However, there is a drawback, namely the researchers get good sensor readings, but the authors only use two parameters[17]. In addition, the study also involved further investigation utilizing visual programming techniques integrated with storage capabilities to SD Card. Through the implementation of this approach, it was observed that the measurement outcomes could be exhibited on both the LDC and Delphi applications. In addition, the author elaborates that the Delphi application functions effectively in presenting data received from the microcontroller through Bluetooth HC-05. This method comes with certain drawbacks. Firstly, the airflow sensor utilized lacks a high level of accuracy. Second, Microsoft Excel does not support automatic data processing, thus manual computations and data processing are required. Lastly, the presentation on the SD Card is not visually appealing[18].

Additionally, the study conducted supplementary research by employing a real-time graphic display approach based on the principles of the Internet of Things. By employing this technique, it was discovered that the tool's design was suitable, as real-time graphics could be used to present measurement data on Thing Speak and the Thing View mobile app, and the accuracy on each sensor had a high level of accuracy, the accuracy value of humidity reached 99.434% at the setting temperature of 36 ° C and the accuracy value of the noise level reached 99.675% on the first measurement. Using this method, there are drawbacks, namely the tool designed is not made portable using rechargeable batteries and the manufacture of temperature sensor holders is not good[19]. Subsequent research conducted research using computer-based monitoring methods for PC and Android applications. By using this method, the results obtained on the Android application can appear in real-time and the sensor used also has a high level of accuracy. By using this method, there are drawbacks, namely the use of toolbox designs that are too large and take up space[20]. Subsequent research also conducts research using real-time communication methods and wireless monitoring. By using this method, results can be obtained that can be displayed on Android in real time and can store the results of sensor reading data. Using this method, there is a drawback, specifically the absence of a graphic display that could facilitate users in observing a stable state more easily[21]. Based on previous research, it can be explained that the comparison of this research with previous research is that this research has development on IOT system that uses Wi-Fi in the process of sending data so that reading results can appear on Thing speak. The benefit of the Thing Speak display lies in its capability to simplify the calibration process monitoring for users[22].

The research aims to develop an advanced Incubator Analyzer, specifically designed as a calibration device, to accurately measure critical parameters including temperature, mattress temperature, humidity, airflow, and noise within infant incubators. The study introduces the Design Incubator

Analyzer for IoT (Mattress Temperature and Humidity) with LCD and ThingSpeak display with a focus on enhancing the calibration process for baby incubators. In summary, this research not only aims to design an effective Incubator Analyzer for infant incubator calibration but also contributes valuable insights into its accuracy, performance against established standards, and the integration of IoT technology for improved user experience. The identified drawbacks pave the way for future research avenues, fostering continual advancements in infant care technology. The contribution of this study is as follows:

1. The primary goal is to design and develop an Incubator Analyzer as a calibration device for infant incubators. Parameters measured include temperature, mattress temperature (TM), humidity, airflow, and noise.
2. The design incorporates a Thermocouple Type-K sensor for mattress temperature, a DHT22 sensor for humidity, and an ESP32 microcontroller for data processing.
3. The ESP32 processes data from sensors to generate values for TM (mattress temperature) and RH (humidity). The results are displayed on both an LCD screen and ThingSpeak platform for user convenience.
4. Rigorous testing was conducted by comparing the Incubator Analyzer to the established INCU II measuring device. The smallest error for mattress temperature occurred at 35°C, with an error of -0.0140%, and the largest error at 36°C, with 0.0584%. Humidity parameter errors ranged from 0.0207% at 35°C to 0.0570% at 32°C.
5. The study concludes that the IoT-based Incubator Analyzer is effective and can be used following proper planning and execution. Integration of IoT for User Convenience. An IoT system was developed to simplify the calibration process, enabling data transmission over Wi-Fi. Results are presented in real-time on the ThingSpeak platform, enhancing user accessibility and monitoring capabilities.

II. METHOD

The Department of Electro-Medical Engineering on the Polytechnic Campus of the Ministry of Health in Surabaya conducted this study. The Fluke INCU II served as the calibrator for the research. The research module was developed using the After Only Design approach[14][23]. Although there was a pre-existing comparison group, this design concentrated on a single-subject group with the primary objective of observing the outcomes without measuring or knowing the baseline conditions. The data collection was conducted using a baby incubator as the medium, taking place in the life support laboratory. Additionally, during the data collection process, room temperature and humidity were measured using a thermometer.

During this research, the temperature within the baby incubator's mattress was monitored using a Type K Thermocouple sensor, while the humidity inside the incubator was measured with a DHT22 sensor. The readings from these sensors were then processed using the ESP32 microcontroller with the Arduino programming language[24]. The results were displayed on an i2C LCD, presenting the values in degrees and percentages, and were also showcased in graphical form on Thingspeak. The temperature of the mattress and the humidity in the incubator served as the dependent factors, while data from the Type K Thermocouple sensor and the DHT22 humidity sensor served as the independent variables[25]. The comparison tool used in this study was the Fluke INCU II.

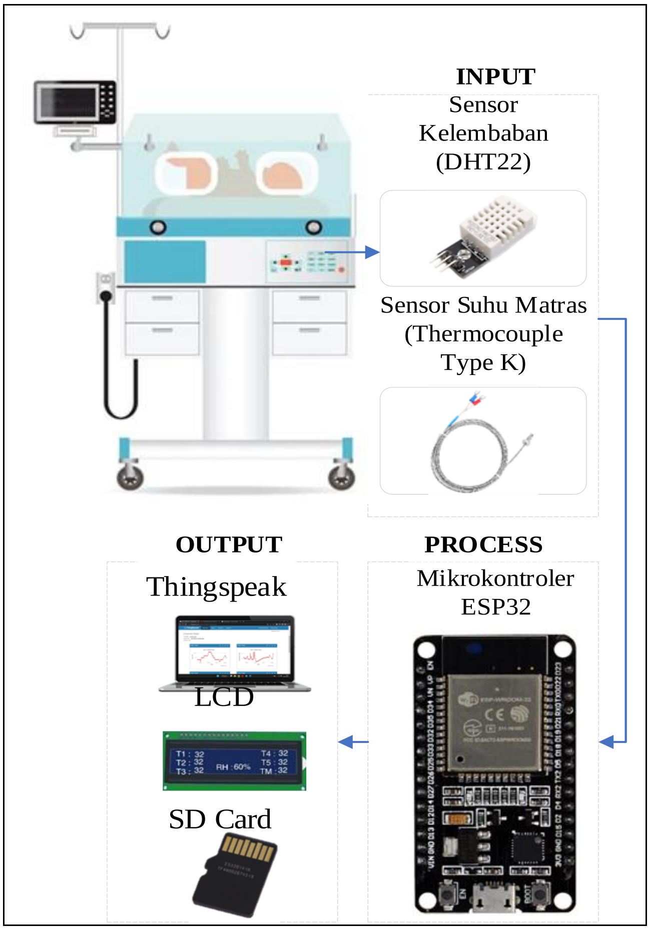

FIGURE 1. The block diagram of the IOT-based Incu Analyzer module system design

In FIGURE 2, when the program initiates, there will be an initialization process performed on both the Type K Thermocouple mattress temperature sensor and the DHT22 humidity sensor. The K-type thermocouple and DHT22 sensors are then used to measure the temperature and humidity of the bedding inside the incubator. If any of the sensors are not detected, the system will revert to the sensor initialization process. Once the Type K and DHT22 Thermocouple sensors have determined the temperature and humidity inside the infant incubator, the collected measurements are delivered as values for both the mattress temperature and humidity. The data for mattress temperature and humidity will be recorded on the SD Card and simultaneously shown on the LCD after the temperature and humidity values have been retrieved. Additionally, the collected data will be transmitted through an internet connection or Wi-Fi to be showcased on the Thing Speak platform. The temperature and humidity reading data will not be communicated to Thing speak if there is no internet or Wi-Fi connection, hence the value will not be seen on the Thing speak interface.

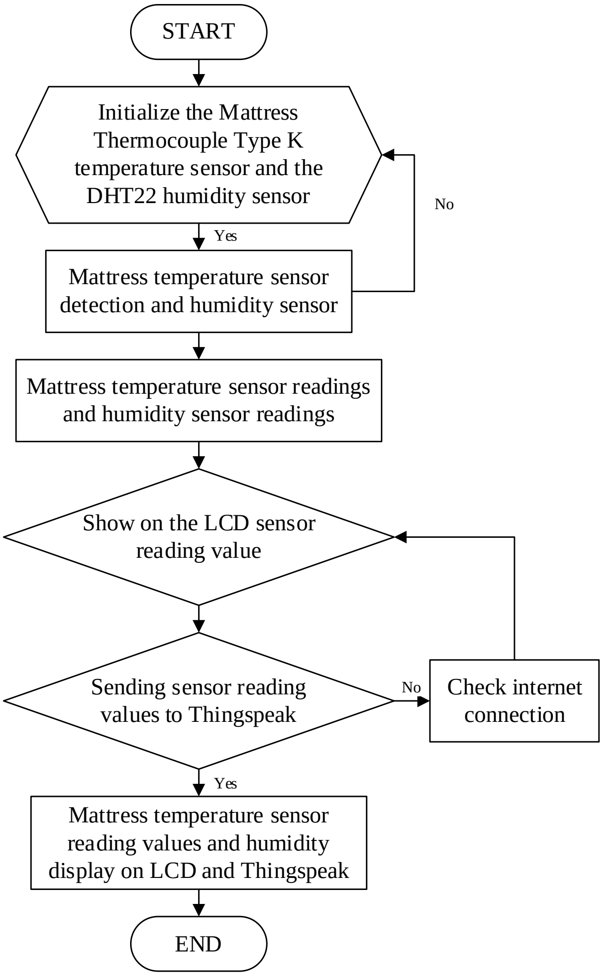

FIGURE 2. The IOT-based Incu Analyzer module's system flowchart

A. DATA ANALYSIS

Each room temperature parameter was measured multiple times (5 times, to be precise). Eq (1) is used to calculate the mean measurement value. To find the mean, divide the total sum of all measurement values by the total number of data points in the collection. "x1" stands for the first measurement in Eq (2), "x2" for the second measurement, and "xn" for the nth measurement. $\overline{x}$ represents the mean of these n measurements. The degree of variation in a data set is quantified by the statistical concept of standard deviation (Sthe D), which expresses the standard deviation from a data collection's mean. The following equation can be used to get the standard deviation= $\sqrt{\frac{\sum(xi-\overline{x})^2}{(n-1)}}$ (1)

The desired parameter's values are denoted by xi in Eq (3), the sum of all measurement results is denoted by x, and the total number of measurements is denoted by n. The variability or uncertainty that arises from each measurement is known as uncertainty (UA). The following is the formula for calculating uncertainty : $UA = \frac{SD}{\sqrt{n}}$ (2)

In Eq (4), "n" stands for the total number of measurements taken, with "UA" representing the uncertainty value generated from the full set of data and "SD" denoting the resulting standard deviation. The difference between each data point's mean value and the percentage error, which indicates the system's error, is used to calculate it. The difference between the standard or model and the actual measurements is represented by the error, which is a measurement. The following is the formula for determining the error: $\%ERROR = \frac{(x_n - x)}{x_n} \times 100\%$ (3)

In this case, "xn" denotes the value acquired from the calibrator machine during the measurement procedure, whereas "x" denotes the value acquired from the design or the predicted value.

III. RESULT

In this research, the performance of the incubator analyzer module, which was developed, was evaluated through testing. The evaluation involved the utilization of a calibrator called Fluke INCU II. FIGURE 3 depicts the layout of the Incubator Analyzer tool. The design of the Incubator Analyzer tool uses an acrylic box covered with stickers to enhance its appearance. The ESP32 microcontroller, which serves as the main component of this module, is equipped with several humidity sensor circuits (DHT22), mattress temperature sensor circuits (Thermocouple Type K), and chamber temperature sensor circuits (DS18B20) that are used to identify incubators for infants. In addition, on the right and left of the incubator analyzer box, there are probes to connect the DS1820 sensor. On the back of the incubator analyzer box, there is also a charger hole which is used to charge the incubator analyzer if the battery runs out late. Then on the right side of the incubator analyzer box, there is an SD Card port for SD Card storage slots. The complete circuit utilized in this investigation is illustrated in FIGURE 4. In this research series, a single lead cable was used to connect each sensor, besides that there was also an ESP32 microcontroller for processing data from sensor readings.

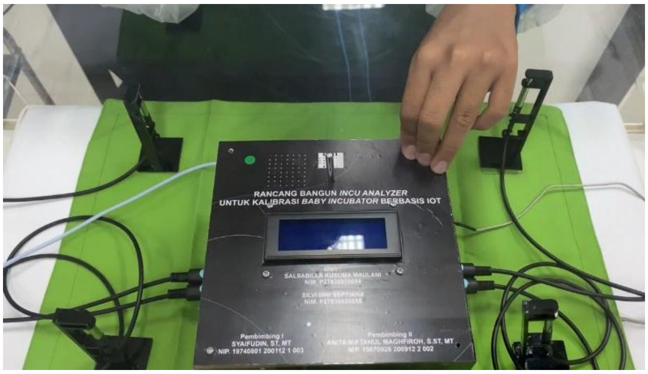

FIGURE 3. The Incu Analyzer module measures the chamber temperature of the baby incubator.

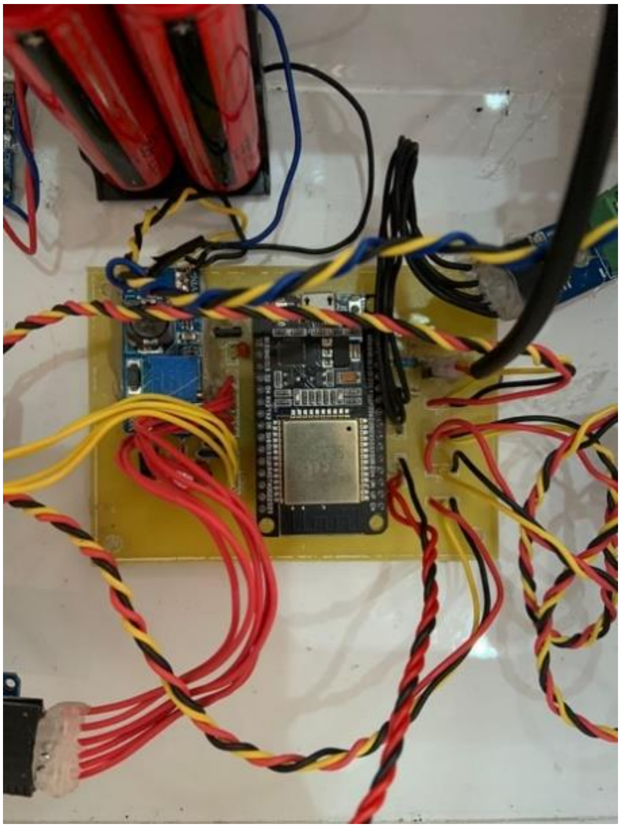

FIGURE 4. Overall circuit design in the Incubator Analyzer module

Room temperature data was taken from the baby incubator in the life support laboratory, Department of Electromedical Engineering, Surabaya. In collecting this data, temperature settings of 32°C, 35°C, and 36°C were used. The error value, STDEV value, and uncertainty value (UA) are calculated from the data collected. Error is the difference between a value that exceeds a module and its actual value. The table below displays the error values for mattress temperature and humidity at various temperature settings. The mattress temperature error observed ranges from -0.0169% at a temperature setting of 32°C to 0.0242% at a temperature setting of 36°C. Similar to temperature, humidity error values range from 0.0154% at 32°C to 0.0508% at 36°C. Detailed information about the temperature parameters of the mattress in the baby incubator can be found in TABLE 1, and for humidity parameters in the baby incubator, refer to TABLE 2. It is worth noting that the obtained error values from the data retrieval remain well within the acceptable tolerance limits.

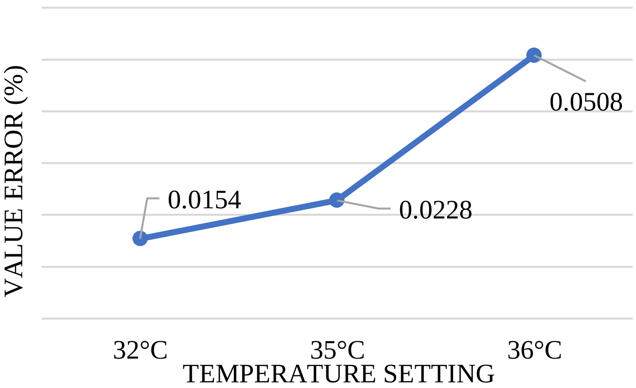

FIGURE 5. The graph displays the mattress temperature parameter's error values at three different temperature settings 32°C, 35°C, and 36°C as determined by the incubator analyzer module.

TABLE 1
Error value for mattress temperature parameter on the module with three temperature settings

Setting Temperature	Error (%)
32°C	-0,0169
35°C	0,0081
36°C	0,0242

TABLE 1 presents the Error values obtained from the researcher's custom-made module for the mattress temperature parameter at three different temperature settings. The study reveals that the highest uncertainty value recorded was 0.0242% when the temperature was set to 36°C.

FIGURE 5 Shows the mattress temperature parameter error graph for the incubator analyzer module, which shows three different temperature settings: 32°C, 35°C, and 36°C.

TABLE 2
Error-values for humidity parameters in modules with three temperature settings

Temperature Setting	Error (%)
32°C	0,0154
35°C	0,0228
36°C	0,0508

TABLE 2 presents the Error values obtained from the researcher's custom-made module for the humidity parameter at three different temperature settings. The study reveals that the highest uncertainty value recorded was 0.0508% when the temperature was set to 36°C.

FIGURE 6 shows the incubator analyzer module's error curve for the humidity parameter, which shows three different temperature settings of 32°C, 35°C, and 36°C.

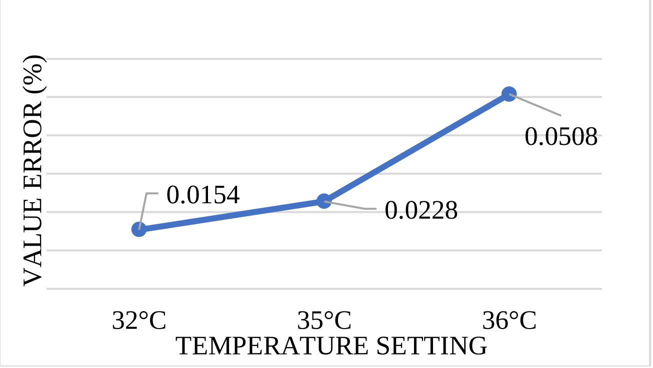

FIGURE 6 **Graph shows humidity parameter error values for temperature settings of 32° C, 35° C, and 36° C**

TABLE 3
Standard Deviation (STDEV) on the temperature parameter of the mattress

Temperature Setting	STDEV
32°C	0,2236
35°C	0,4324
36°C	0,3420

TABLE 3 presents the Standard Deviation (STDEV) values obtained from the researcher's custom-made module for the mattress temperature parameter at three different temperature settings. According to the study, when the temperature was set to 35°C, the maximum standard deviation value was 0.4324, and when the temperature was set to 32°C, the lowest standard deviation value was 0.2236.

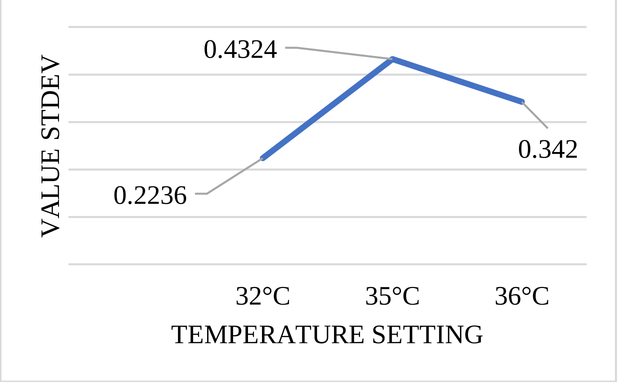

FIGURE 7. **The graph shows the standard deviation values for the mattress temperature parameter for the incubator analyzer module for the three distinct temperature settings of 32°C, 35°C, and 36°C.**

FIGURE 7 represents a graph that shows the standard deviation of the baby incubator mat's temperature parameters at the three distinct temperature settings of 32°C, 35°C, and 36°C.

TABLE 4 presents the Uncertainty (UA) values obtained from the modules developed by the researchers for the mattress temperature parameters at three different temperature settings. According to the study, with a temperature setting of 35°C, the highest UA value was recorded at 0.1933, while the lowest UA value was recorded at 0.0081 at a temperature setting of 36°C.

TABLE 4
Uncertainty Comparison Value (UA) on the temperature parameter of the mattress

Temperature Seting	UA
32°C	0,0997
35°C	0,1933
36°C	0,0081

FIGURE 8 is a graph that shows the Uncertainty (UA) of the baby incubator mat's temperature parameters about the three different temperature settings of 32°C, 35°C, and 36°C.

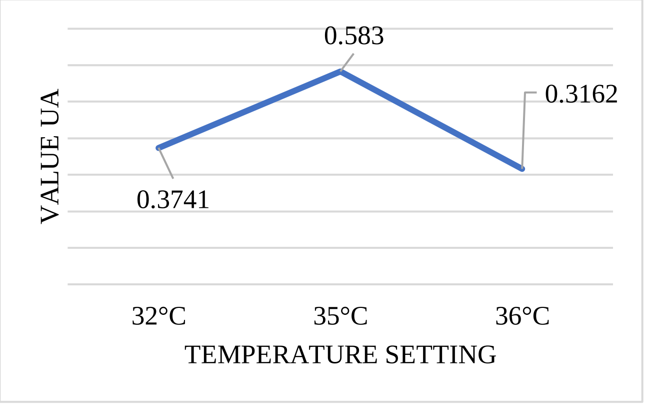

FIGURE 8. **The graph shows the Uncertainty (UA) values for the mattress temperature parameter for the three distinct temperature settings of 32°C, 35°C, and 36°C for the incubator analyzer module.**

TABLE 5
Standard Deviation (STDEV) on the humidity parameter

Temperature Setting	STDEV
32°C	0,8366
35°C	1,3038
36°C	0,7071

TABLE 5 presents the Standard Deviation (STDEV) values obtained from the module developed by the researchers for the baby incubator humidity parameter at three different temperature settings. The investigation found that the largest standard deviation value was 1.3038 at a temperature setting of 35°C and the smallest standard deviation value was 0.7071 at a temperature setting of 36°C.

FIGURE 9 shows a graph of the standard deviation for the humidity parameters of a baby incubator at the three different temperature settings of 32°C, 35°C, and 36°C for the incubator analyzer module.

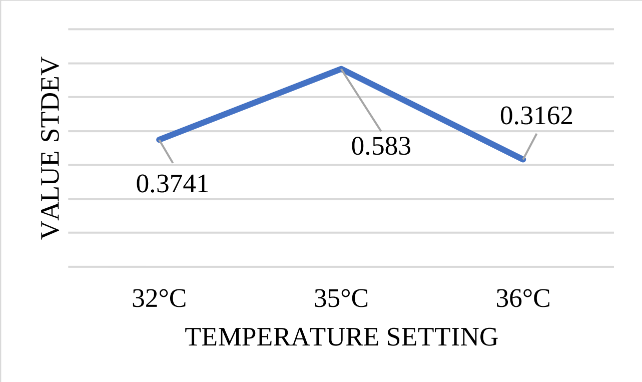

FIGURE 9. The graph displays the humidity parameter's standard deviation values for three different temperature settings: 32°C, 35°C, and 36°C. These values were collected from the incubator analyzer module.

TABLE 6
Uncertainty Comparison Value (UA)) on the humidity parameter

Temperature Setting	UA
32°C	0,3741
35°C	0,5830
36°C	0,3162

The Uncertainty (UA) values for the humidity parameters of the infant incubator at three distinct temperature settings are shown in TABLE 6 according to the module created by the researcher. According to the study, the highest UA value ever observed was 0.5830 with a temperature setting of 35°C, and the lowest UA value ever observed was 0.3162 at a temperature setting of 36°C.

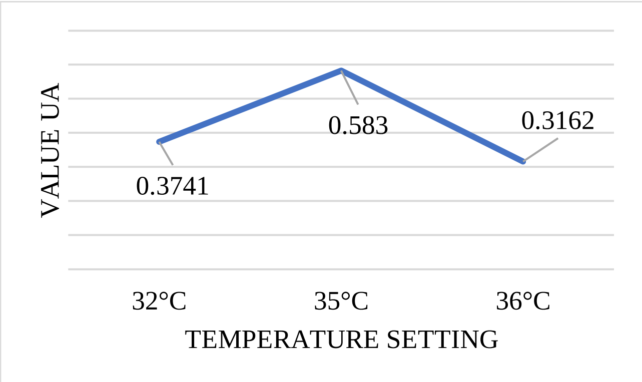

FIGURE 10. The graph shows the Uncertainty (UA) values for the humidity parameter at the three distinct temperature settings of 32°C, 35°C, and 36°C as determined by the incubator analyzer module.

FIGURE 10 A graph showing the Uncertainty (UA) of the incubator analyzer module about the humidity parameters of a baby incubator at three distinct temperature settings 32°C, 35°C, and 36°C s shown.

IV. DISCUSSION

In the course of this study, the module's output was compared to that of the Fluke INCU II over a 60-minute duration at each temperature setting, involving a total of 5 measurements[26]. To assess the stability and accuracy of the module's manufacturing, data were collected, the Incubator Analyzer module was measured, and the findings were meticulously examined. An attempt was made to test each component to ensure it fulfills its intended function. Subsequently, error values for each parameter were determined, with the maximum error for the mattress temperature parameter recorded at 0.0242% at a temperature setting of 36°C, and the largest error for humidity reported at 0.0508% at the same temperature. Despite these errors, the overall results fall within tolerance limits, affirming the feasibility of the tool. The study introduces the terms "standard deviation" in tachometer calibration and "uncertainty" to gauge the tachometer module's accuracy in determining centrifuge speed. The accuracy and consistency of the measurement results exhibit an inverse correlation with standard deviation and standard uncertainty values.

The primary objective of this project is to develop an incubator analyzer that utilizes the language of the Internet of Things (IoT), specifically ThingSpeak, to simplify the calibration process for consumers. This research addresses a gap in prior studies by introducing the Incubator Analyzer with an IoT display, making it easier for consumers to calibrate baby incubators. A noteworthy distinction from previous research is the incorporation of an Internet of Things system for calibration monitoring in this study[27].

The authors acknowledge the weaknesses in the module's development and express hope for future corrections and improvements. One notable weakness lies in the ThingSpeak platform's inability to store data. Additionally, the SD Card storage created by the author is in a basic text display format for the Incubator Analyzer module. The authors anticipate that further research will address these weaknesses, urging a change in the Internet of Things platform and the appearance of the SD Card.

It's important to note that this investigation exclusively focuses on the Internet of Things display. The study underscores that without an internet connection during measurements, the device cannot display IoT data via ThingSpeak. This emphasizes the significance of calibrating baby incubators by monitoring through a smartphone or laptop. The design of the incubator analyzer calibration tool, equipped with an Internet of Things display in the form of ThingSpeak, is highlighted as a means to simplify the calibration process.

The limitations of this research showed result comparison between the Incubator Analyzer and the Fluke INCU II is confined to five temperature settings, each lasting 60 minutes. This restricted number of measurements and conditions may not fully capture the device's performance across diverse scenarios and environmental variations and this aims to evaluate stability and accuracy, the research primarily concentrates on error values for mattress temperature and humidity. Other factors influencing stability and accuracy under different operational conditions remain underexplored. The Incubator Analyzer's reliance on an internet connection for real-time monitoring via ThingSpeak poses a limitation, hindering the display of IoT data when the device is not connected to the internet, the ThingSpeak platform is highlighted, particularly its inability to store data. This limitation may impact the system's long-term data retention capabilities, crucial for continuous monitoring and analysis. Implementing an SD Card storage solution, the format is restricted to basic text (txt) display. The absence of a more sophisticated data storage format may limit the efficiency and practicality of data retrieval and analysis, indicating a need for improvement. This research has been compared with previous research, namely Naily Nurrohmah's, which used Bluetooth and data storage to monitor incubator parameters, where the difference in temperature measurement error with setting 36^0C was greater than what the author did[12].

IV. CONCLUSION

An incubator analyzer with Internet of Things capabilities will be built using WiFi data transmission and an ESP32 microcontroller in this study's goal. In this study, a K-type thermocouple sensor was used to measure the mattress temperature of an infant incubator, and a DHT22 sensor was used to measure the humidity level. The STDEV values for the Type K thermocouple sensor module are 0.4324 at 36°C and 0.2336 at 32°C, respectively. The STDEV values for the DHT22 sensor module are 1.3038 at 35°C and 0.7071 at 36°C, respectively. The Type K thermocouple sensor module displayed the study's highest and lowest UA values, respectively 0.1933 at a temperature setting of 35°C and 0.0997 at a setting of 32°C. The greatest UA value was recorded by the DHT22 sensor module at a temperature setting of 35°C, and the lowest UA value was recorded at a setting of 36°C, both of which were 0.3162.

The module was put through testing, and the findings showed that it performed well and worked as intended when the measurements were compared using the Fluke INCU II comparison tool. This research has a development on its IOT system that uses Wifi in the process of sending data so that reading results can appear on Thingspeak. One of the benefits of using the Thingspeak display is its ability to simplify the calibration process monitoring for users.

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