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Design of Incu Analyzer for IoT-based Baby Incubator Calibration

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ABSTRACT Incubator Analyzer is a calibration tool that measures baby incubators' temperature, mattress temperature, humidity, airflow, and sound level. This research aims to design an "Incu Analyzer for IOT-based Baby Incubator Calibration (Chamber Temperature)" tool with an LCD and Thingspeak integration. The design of this calibration tool involves the baby incubator chamber temperature parameters, namely T1, T2, T3, T4, and T5, which are measured using the DS18B20 sensor. The ESP32 microcontroller is employed to leverage the IoT system, and Wi-Fi is used for IoT communication. The ESP32 processes data collected from the DS18B20 temperature sensor and displays it on the LCD and Thingspeak. This tool is tested by comparing the incubator analyzer module with a standard measuring instrument, INCU II. The temperature parameter yielded the smallest error value of -0.059293% at T5 with a setting temperature of 36°C and the largest error value of -0.0254188% at T2 with a setting temperature of 35°C. In conclusion, after conducting a comprehensive study of the literature and planning, it can be affirmed that the "Incu Analyzer Design for IOT-Based Baby Incubator Calibration" tool functions as planned, demonstrating its efficacy as an IoT-based Incubator Analyzer. This research has successfully developed an IoT system that utilizes Wi-Fi to transmit data and display reading results on Thingspeak, which significantly facilitates users in monitoring the calibration process.

INDEX TERMS Incubator Analyzer, Baby Incubator, ESP32, DS18B20.

I. INTRODUCTION

Over time, almost every aspect of human existence has become intertwined with technology. In the current digital age, the rapid advancements in Digital Technology have brought about instant and swift changes in life. The advent of the Fourth Industrial Revolution has had a transformative impact on all spheres of human endeavor [1]. Technological progress has far-reaching effects on diverse aspects of life, including economics, politics, culture, and health. Today, technology and human life are in sync, with technology continually evolving with scientific advancements. Advancements in education play a pivotal role in fostering innovative generations that contribute positively to society. Moreover, technological developments have also revolutionized various human activities, particularly in electronics [2].

The progress of electronic technology has brought numerous advantages to human existence. Particularly in health, advancements in electronic technology play a crucial role in upholding public health standards [3]. The continuous development of health-related technology has significantly improved the well-being of people worldwide. Technology and the internet have greatly facilitated access to information and resources, empowering individuals to take charge of their health and well-being [4].

A notable example of technological advancement is the capability to remotely control electronic devices, leading to substantial convenience in performing everyday tasks for humans. The Internet of Things (IoT) definition is a concept developed to give more benefits to continuous and wireless [5]. IoT enables data transfer across networks without the need for direct human involvement. This technological advancement holds great potential for revolutionizing the healthcare sector, inspiring innovative ideas and solutions in the realm of health [6].

Health, particularly concerning premature babies, is paramount and demands attention. Indonesia's infant mortality rate remains significantly high, with over 400 infants aged 0-11 months succumbing to various factors [7]. The Ministry of Health attributes the high infant mortality rate to several causes, including many young mothers giving birth [8]. Additionally, the large number of births contributes to the issue. Low birth weight is another critical factor leading to infant mortality. Infants in this category have a birth weight below 2500 grams and a gestational age of fewer than 37 weeks [9]. Premature birth poses numerous risks to the newborn's health, and the level of risk increases with earlier gestational age [10]. Babies with low birth weight frequently face difficulties developing their organ functions, which are crucial for acclimatizing to life beyond the womb [11]. These infants require intensive care, as they are highly susceptible to hypothermia and organ immaturity, primarily contributing to premature infant mortality [12]. To stabilize the condition of premature babies, specialized monitoring and care are crucial, involving using a device known as a baby incubator, which provides the necessary warmth and support [13]. This technology aids in providing a controlled environment to help the newborns grow and develop, increasing their chances of survival and ensuring optimal health outcomes.

The crucial role of a baby incubator lies in creating a controlled environment for babies with premature or infants' weight low when birth. The incubator achieves this by carefully regulating temperature and humidity levels within the chamber, effectively emulating the conditions of the mother's uterus [14]. This controlled environment is particularly beneficial for babies experiencing hypothermia, as it helps properly develop their delicate skin and reduces the risk of infections by limiting direct contact with external individuals [15]. In order to safeguard the well-being of the baby and maintain stable temperature conditions, the incubator is usually adjusted to maintain a normal temperature within the range of approximately 33°C to 35°C while ensuring humidity levels are kept around 40% to 60% [16]. Regular maintenance is crucial to uphold the quality and reliability of the equipment. Calibration is one essential aspect of such maintenance efforts, helping to ensure that the incubator operates accurately and consistently to provide the best possible care for these vulnerable infants.

Calibration is an essential process used to confirm the accuracy of testing instruments or materials by comparing data with traceable measuring standards, which can either be national or international [17]. Permenkes No.54 of 2015, which addresses the testing and calibration of medical devices, emphasizes the significance of these processes in ensuring that medical devices adhere to service standards, quality requirements, and safety regulations and are appropriate for their intended use [18]. The testing and calibration results provide information on the extent of deviation from the designated value. Based on this deviation value, relevant bodies or institutions can determine whether the device is still suitable. This process is crucial in maintaining the security and safety of the medical equipment and the patients who rely on them.

A specific instrument known as an "in analyzer" is used to calibrate baby incubators. The incur analyzer is specially designed to evaluate the efficiency and safety of baby incubators by continuously monitoring essential parameters, including temperature, humidity, noise, and airflow [19]. Through the application of the incur analyzer, healthcare experts can guarantee that the baby incubator functions at its best, ensuring the maintenance of the necessary conditions for providing care to premature infants and babies with low birth weight. This process is essential in safeguarding the well-being of these vulnerable newborns during their crucial early developmental stages.

According to the references accessed, the research uses the System Development Life Cycle (SDLC) method, which includes the stages of planning, needs analysis, design, implementation, testing, and analysis of design results. This method achieved a high accuracy level of 99.18% with a 0.82% error rate for temperature readings, and the uncertainty value was ±0.015101°C. Similarly, for moisture readings, the uncertainty value was ±0.134326%RH. These results indicated that the parameters were performed with exceptional accuracy. However, a limitation was noted as the study focused only on two parameters [20]. More in-depth research involves the use of visual programming methods that are integrated with storage using an SD card. This approach allowed measurement results to be displayed on an LDC and a Delphi application. The Delphi application successfully displayed data received from the microcontroller via Bluetooth HC-05. While the method exhibited potential, the accuracy of the airflow sensor was not as satisfactory, and there was an absence of automatic data processing through Microsoft Excel, necessitating manual computations.

Moreover, the presentation on the SD Card could have been more visually appealing [21]. Furthermore, the research will utilize the Internet of Things (IoT) based real-time graphical display method. This method resulted in well-designed tools that displayed real-time measurements on Thingspeak and the ThingView smartphone application. The accuracy levels for each sensor were notably high, reaching 99.434% for humidity at 36°C setting temperature and 99.675% for noise level on the first measurement. Nonetheless, drawbacks were identified, including the lack of portability with rechargeable batteries and subpar temperature sensor holder design [22]. The next researcher will look for monitoring methods using computers with applications that can be accessed via PCs and Android devices. The results obtained in the Android application were displayed in real-time, and the sensors used demonstrated high accuracy. However, the design of the toolbox was excessively large, occupying substantial space [23]. Subsequent research will use wireless technology to apply real-time communication and monitoring methods, resulting in data that can be displayed directly on Android devices and store sensor reading data. Nevertheless, a drawback was noted in the absence of a graphic display that would facilitate users in observing a stable state [24]. In conclusion, while there are several research efforts in this field, the utilization of the Internet of Things method remains relatively limited, according to the available journals.

The literature review reveals that several previous researchers still need to implement IoT-based graph displays. As a result, this research aims to create an Incu Analyzer Design for IoT-Based Baby Incubator Calibration, focusing on room temperature. The objective is to display room temperature values on the LCD screen and the Thingspeak platform, facilitating doctors, midwives, and nurses to observe stable conditions [25]. For this purpose, the study utilizes DS18B20 sensors to detect room temperature in baby incubators.

II. METHODOLOGY

The research occurred at the Department of Electromedical Engineering, Surabaya Campus, where the Fluke INCU II was utilized as the calibrator. The study employed an After Only Design type research design with a single group of subjects. Only the outcomes were observed during the study without measuring or knowing the initial conditions, while a comparison group was also incorporated.

This research explains that the DS18B20 sensor was employed to detect the chamber temperature in the baby incubator. The readings from the sensor were subsequently processed using the ESP32 microcontroller and displayed on both the LCD screen and the Thingspeak platform. The variable of interest was the chamber temperature of the baby incubator, while the independent variable was the temperature measured by the DS18B20 sensor. The Fluke INCU II was used as the reference tool in this research for comparison purposes.

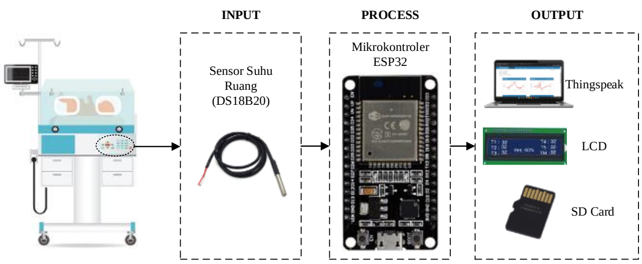

FIGURE 1. The diagram block of the system in the design of the IoTIOT-based Incu Analyzer module

FIGURE 1 displays a block diagram of three main components: input, process, and output. The input section integrates the chamber temperature of the baby incubator, which is detected by the DS18B20 sensor. This sensor serves as the source of input data, which is then transmitted to the microcontroller for processing. The process involves a microcontroller responsible for receiving and handling the data from the sensor. In the output process, two displays are utilized: an LCD and a Thingspeak display. These displays showcase the sensor readings processed by the microcontroller, ensuring the information is easily accessible and understandable. FIGURE 2 illustrates a flow chart depicting the step-by-step actions. The process begins with activating the ON button, which initiates the sensor initialization process. Once the initialization is finished, the process proceeds to sensor detection. If the condition is false, indicating a sensor issue, the process returns to the initialization step to address the problem. Conversely, if the condition is true, implying successful sensor detection, the process continuously detects and displays sensor reading values, providing real-time information to users. This flow chart outlines the step-by-step actions necessary to ensure the proper functioning of the system and the continual display of critical data.

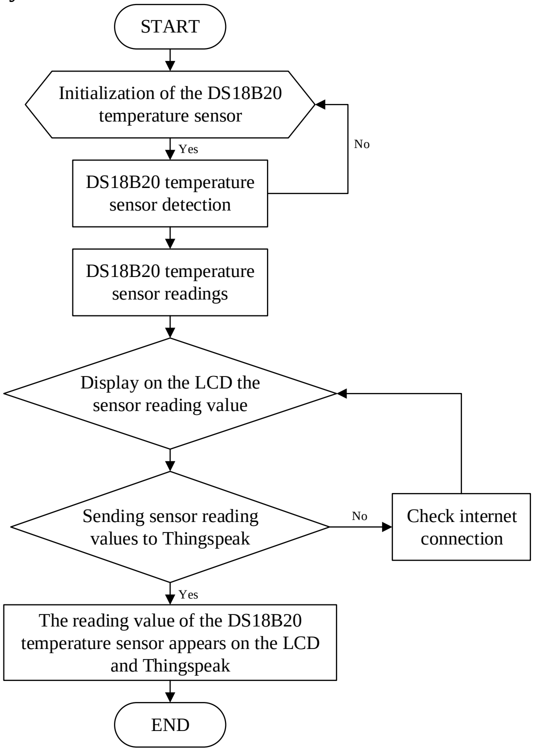

FIGURE 2. The flowchart system in the design of the IoTIOT-based Incu Analyzer module

A. DATA ANALYSIS

The room temperature parameters were subjected to multiple measurements, specifically five times. The mean measurement value is calculated using Eq (1), which divides the total of all values by the data points.

$$\overline{x} = \frac{x1+x2\ldots+xn}{n} \quad (1)$$

Eq (2) features symbols such as $\overline{x}$, which denotes the mean of n-measurements, and x1, x2, up to xn, representing the first, second, and nth measurements, respectively. Standard deviation is a numerical value that indicates the level of variation in the dataset or measures how the data deviates from the mean. The formula for calculating the standard deviation (STDEV) is presented as shown in Eq (2).

$$STDEV = \sqrt{\frac{\sum(xi-\bar{x})^2}{(n-1)}} \quad (2)$$

Within Eq (3), xi refers to the expected values, x represents the mean value of the measured results, and n indicates the measurements. Uncertainty (UA) refers to the doubt or variability in each measurement result. The formula for calculating uncertainty is represented as shown in Eq (3).

$$UA = \frac{SD}{\sqrt{n}} \quad (3)$$

Moreover, in Eq (4), UA represents the uncertainty value of the overall measurement, SD represents the standard deviation of the results, and n indicates the measurement range. %error is a parameter that indicates system errors. The lower error value signifies the disparity between the means of each dataset. This error value can indicate a deviation between the specification and the design or model. The formula for calculating the error is presented as shown in Eq (4).

$$\%ERROR = \frac{(x_n - x)}{x_n} \times 100\% \quad (4)$$

Lastly, in the provided equation, xn denotes the value obtained from the calibrator device, while x represents the value measured by the design.

III. RESULT

The developed module underwent testing with this study's calibrator known as Fluke INCU II. The module's design is depicted in FIGURE 3. The central element of this module is the ESP32 microcontroller [24], which integrates a series of DS18B20 sensors for chamber temperature detection, a series of DHT22 sensors for humidity measurement, and a series of Type K Thermocouple sensors for monitoring mattress temperature.

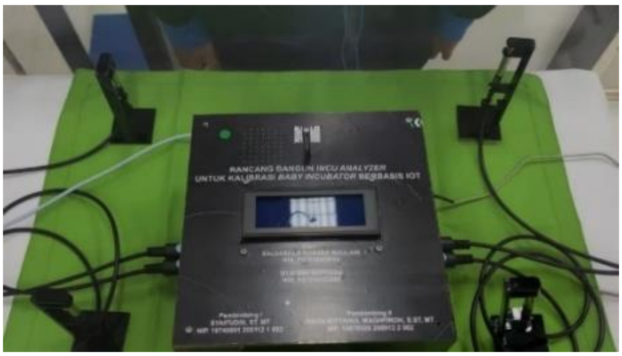

FIGURE 3. The Incu Analyzer module measures the chamber temperature of the baby incubator

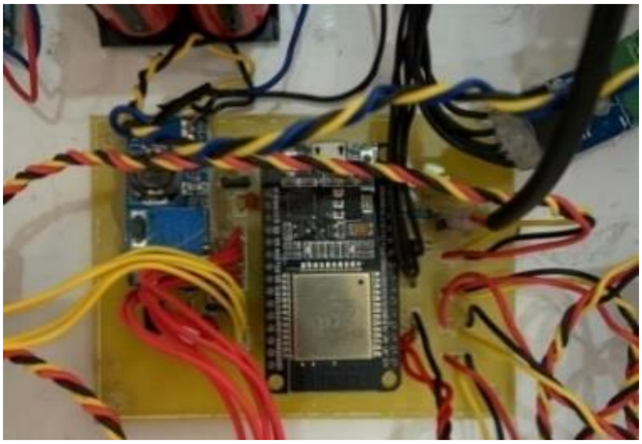

FIGURE 4. Overall circuit design in the Incu Analyzer module

Room temperature data was collected from a baby incubator in the life support laboratory Department of Electromedical Engineering, Surabaya. Data collection involved temperature settings of 32°C, 35°C, and 36°C, each with five data retrievals. By calculating the difference in measurement values from the five data points, error values were obtained for each temperature setting, representing the variation between the actual value and the module's reading. TABLE 1 presents the error values for the 32°C temperature setting, and their comparison is shown in FIGURE 5.

TABLE 1
Error value for each point or position of the sensor on the module at the baby incubator temperature setting of 32°C

Sensor Position	Error
T1	-0,0392278%
T2	-0,0294486%
T3	-0,0357142%
T4	-0,0376884%
T5	-0,0439974%

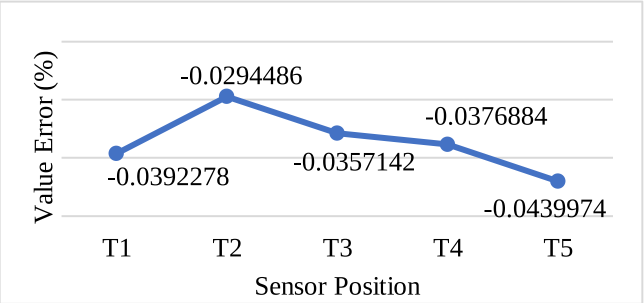

FIGURE 5. Graph of the error value for each point or position of the sensor on the module at the baby incubator temperature setting of 32°C

FIGURE 5 illustrates the error values for the 35°C temperature setting, where the highest error value is -0.0294486% at T2, and the lowest error value is -0.0439974% at T5. TABLE 2 presents the error values for each data point at the temperature setting of 35°C, and their comparison is depicted in FIGURE 6.

TABLE 2
Error value for each point or position of the sensor on the module at the baby incubator temperature setting of 35°C

Sensor Position	Error
T1	-0,0317821%
T2	-0,0254188%
T3	-0,0294117%
T4	-0,0348028%
T5	-0,04629%

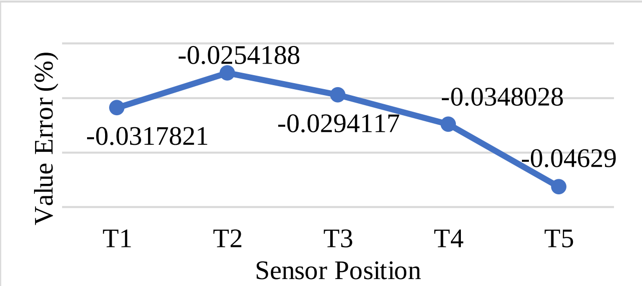

FIGURE 6. Graph of the error value for each point or position of the sensor on the module at the baby incubator temperature setting of 35°C

FIGURE 6 displays the error values for the 35°C temperature setting, where the highest error value is -0.0254188% at T2, and the lowest error value is -0.04629% at T5. TABLE 3 presents the error values for each data point at the temperature setting of 36°C, and their comparison is shown in FIGURE 7.

TABLE 3
Error value for each point or position of the sensor on the module at the baby incubator temperature setting of 36°C

Sensor Position	Error
T1	-0,0473802%
T2	-0,039818%
T3	-0,0455063%
T4	-0,0491991%
T5	-0,059293%

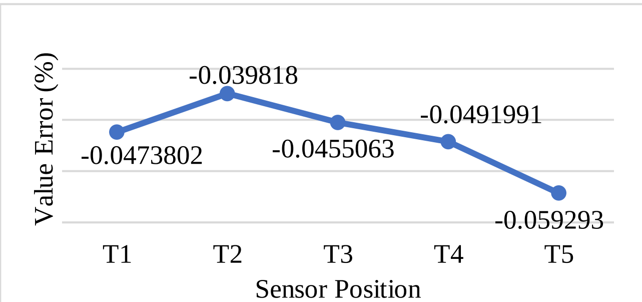

FIGURE 7. Graph of the error value for each point or position of the sensor on the module at the baby incubator temperature setting of 36°C

FIGURE 7 presents the error values for the 36°C temperature setting, where the highest error value is -0.039818% at T2, and the lowest error value is -0.059293% at T5. TABLE 4 displays the standard deviation values (STDEV) obtained from the module developed by the researcher for the room temperature parameter at a temperature setting of 32°C, and their comparison is shown in FIGURE 8.

TABLE 4
Standard deviation (STDEV) value for each sensor point or position on the module at the baby incubator temperature setting of 32°C

Sensor Position	STDEV
T1	0,109545
T2	0,0894427
T3	0,114018
T4	0,0894427
T5	0,342053

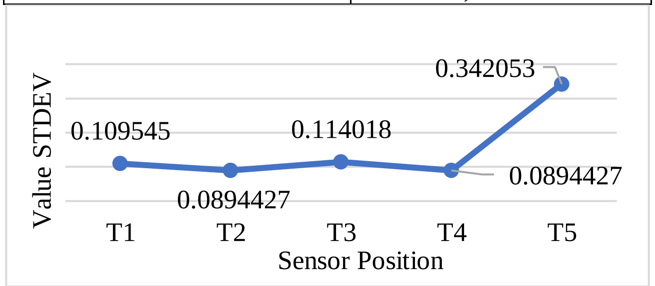

FIGURE 8. Graph of the STDEV value for each point or position of the sensor on the module at the baby incubator temperature setting of 32°C

FIGURE 8 illustrates that the highest standard deviation (STDEV) value is 0.342053 at T5, and the lowest standard deviation (STDEV) value is 0,089447 at T2 and T5. TABLE 5 presents the standard deviation values (STDEV) obtained from the researcher's module for the room temperature parameter at a temperature setting of 35°C, and their comparison is shown in FIGURE 9.

TABLE 5
Standard deviation (STDEV) value for each sensor point or position on the module at the baby incubator temperature setting of 35°C

Sensor Position	STDEV
T1	0,0547723
T2	0,0707107
T3	0,0707107
T4	0,0447214
T5	0,230217

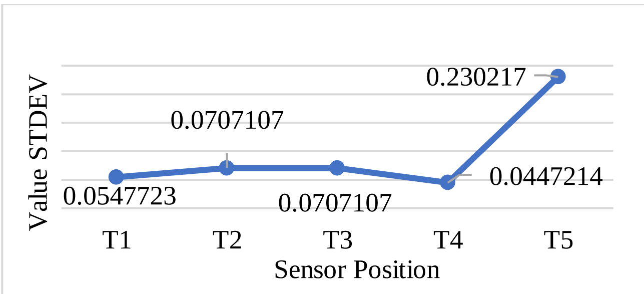

FIGURE 9. Graph of the STDEV value for each point or position of the sensor on the module at the baby incubator temperature setting of 35°C

FIGURE 9 indicates that the highest standard deviation (STDEV) value is 0.230217 at T5, and the lowest standard deviation (STDEV) value is 0,0447214 at T2. TABLE 6 displays the standard deviation values (STDEV) obtained from the researcher's module for the room temperature parameter at a temperature setting of 36°C, and their comparison is depicted in FIGURE 10.

TABLE 6
Standard deviation (STDEV) value for each sensor point or position on the module at the baby incubator temperature setting of 36°C

Sensor Position	STDEV
T1	0,0447214
T2	0,0894427
T3	0,114018
T4	0,0447214
T5	0,181659

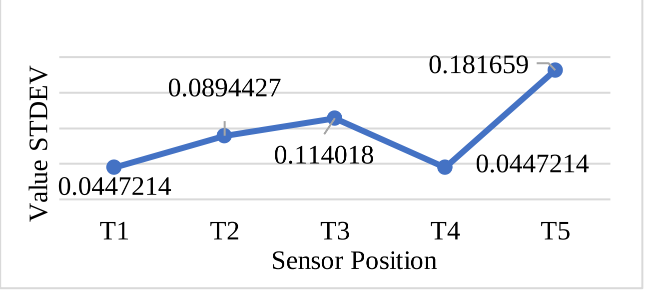

FIGURE 10. Graph of the STDEV value for each point or position of the sensor on the module at the baby incubator temperature setting of 36°C

FIGURE 10 shows that the highest standard deviation (STDEV) value is 0.181659 at T5. TABLE 7 presents the uncertainty values (UA) obtained from the researcher's module for the room temperature parameter at a temperature setting of 32°C, and their comparison is shown in FIGURE 11.

TABLE 7
Uncertainty (UA) value for each sensor point or position on the module at the baby incubator temperature setting of 32°C

Sensor Position	UA
T1	0,04899
T2	0,04
T3	0,0509904
T4	0,04
T5	0,152971

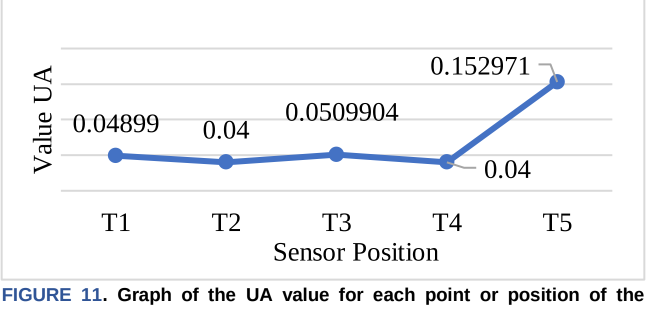

FIGURE 11. Graph of the UA value for each point or position of the sensor on the module at the baby incubator temperature setting of 32°C

FIGURE 11 indicates that the highest uncertainty value (UA) is 0.152971 at T5. TABLE 8 presents the uncertainty values (UA) obtained from the researcher's module for the room temperature parameter at a temperature setting of 35°C, and their comparison is shown in FIGURE 12.

TABLE 8
Uncertainty (UA) value for each sensor point or position on the module at the baby incubator temperature setting of 35°C

Sensor Position	UA
T1	0,0244949
T2	0,0316228
T3	0,0316228
T4	0,02
T5	0,0812404

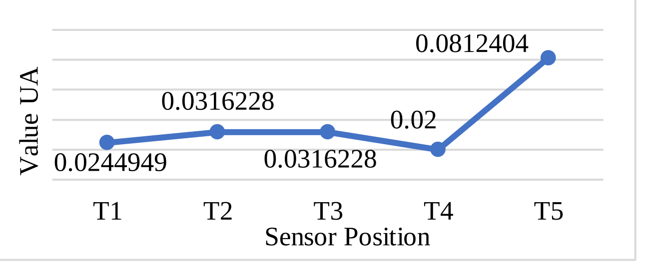

FIGURE 12. Graph of the UA value for each point or position of the sensor on the module at the baby incubator temperature setting of 35°C

FIGURE 12 demonstrates that the highest uncertainty value (UA) is 0.152971 at T5. TABLE 9 displays the uncertainty values (UA) obtained from the researcher's module for the room temperature parameter at a temperature setting of 36°C, and their comparison is shown in FIGURE 13.

TABLE 9
Uncertainty (UA) value for each sensor point or position on the module at the baby incubator temperature setting of 36°C

Sensor Position	UA
T1	0,0199998
T2	0,04
T3	0,0509904
T4	0,02
T5	0,102956

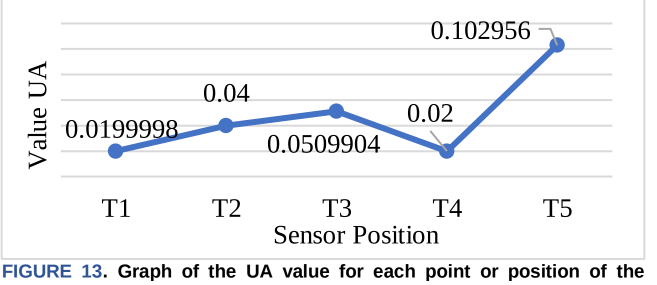

FIGURE 13. Graph of the UA value for each point or position of the sensor on the module at the baby incubator temperature setting of 36°C

FIGURE 13 indicates that the highest uncertainty value (UA) is 0.152971 at T5. Based on the results obtained, the study concludes that the largest error value is -0.0254188% at T2 with a temperature setting of 35°C, and the largest standard deviation value (STDEV) is 0.342053 at T5 with a temperature setting of 32°C. The largest uncertainty value (UA) is 0.152971 at T5 with a temperature setting of 32°C.

IV. DISCUSSION

Measurements were performed by comparing the module's outcomes with Fluke INCU II, with each temperature setting lasting 60 minutes and data collected five times for each setting. As a result, error values were obtained for each parameter. The highest error value for room temperature was -0.0254188% at T2 with a temperature of 35°C, and the smallest error value was -0.059293% at T5 at 36°C. For mattress temperature, the error value was 0.0242% at 36°C, while the largest error for humidity was 0.0508% at 36°C.

Analyses data aims to make an Incu Analyzer equipped with IoT Thingspeak, making it easier for users to calibrate. This research is valuable as it addresses the need for previous studies and developments related to the Incu Analyzer with an IoT display. By doing so, it aims to enhance the calibration process for users of baby incubators, offering a more convenient and efficient approach. In this study, a notable distinction from previous research is implementing an IoT system for calibration monitoring. Unlike previous studies, this research incorporates an IoT display, enhancing the efficiency and capabilities of the calibration process.

The author is fully aware of the weaknesses in making this module. Therefore, the authors hope that these weaknesses can be corrected and further improved in the future. The following is the weakness of the module made by the author, namely on the Thingspeak platform, because Thinspeak cannot store data. Besides that, in the Incu Analyzer module, the author made, there is an SD Card storage still in the form of a text display. Therefore, it is hoped that further researchers will change the IoT platform and the SD Card's appearance.

This study only focuses on the IoT display. At the time of measurement, if the device is not connected to an internet connection, the device cannot display IoT in the form of Thingspeak. This finding emphasizes the importance of calibrating baby incubators via smartphone or laptop monitoring. The incur analyzer calibration tool designed with an IoT display in Thingspeak can simplify the calibration process.

IV. CONCLUSION

The primary aim of this research was to design an IoT-based Incubator Analyzer that utilizes Wi-Fi data transmission on the ESP32 microcontroller. The DS18B20 sensor was employed to detect chamber temperature in baby incubators, and the largest error value recorded was -0.0254188% at T2 with a temperature setting of 35°C, whereas the smallest error value was -0.059293% at T5 with a temperature setting of 36°C. Regarding standard deviation (STDEV), the highest value obtained was 0.342053 at T5 with a temperature setting of 32°C, and the lowest was 0.181659 at T5 with a temperature setting of 36°C. Furthermore, for uncertainty (UA), the largest value was 0.152971 at T5 with a temperature setting of 32°C, and the smallest value was 0.0812404 at T5 at 36°C. The module underwent testing by comparing its measurement results with the Fluke INCU II comparison tool, and the outcomes indicated that the module operates effectively and can be deemed satisfactory. A notable advancement in this study was introducing an IoT system with Wi-Fi data transmission and displaying readings on Thingspeak. Utilizing the Thingspeak display offers the benefit of facilitating user monitoring of the calibration process. For future developments, exploring a more efficient IoT platform capable of storing measurement and development data on the tool is recommended. Additionally, considering the inclusion of airflow and noise parameters and further enhancing the use of the LCD can be valuable areas for improvement.

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