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Monitoring Baby Incubator Central Based Raspberry Pi Zero W with Temperature and Skin Temperature Parameter Based on IoT

Fransiska Ima Setia Ningsih[1], Bambang Guruh Irianto[1], Lamidi[1], and Mohanad Abdulhamid[2]

[1] Department of Electromedical Engineering Poltekkes Kemenkes, Surabaya Jl. Pucang Jajar Timur No. 10, Surabaya, 60245, Indonesia
[2] Al-hikma University, Yarmook Street Intersection, Baghdad, Iraq

Corresponding author: Lamidi (e-mail: justlamidi@gmail.com).

ABSTRACT This research is dedicated to enhancing the quality of care provided to vulnerable infants by proactively addressing potential challenges. The goal is to recreate the optimal environmental conditions resembling the mother's womb—ensuring precise maintenance of temperature, humidity, and oxygen levels—through the utilization of infant incubators. The primary objective of this study revolves around the development of an autonomous monitoring tool tailored for midwives and healthcare personnel responsible for overseeing multiple infant incubators. Driven by the synergy of an ESP32 module and Raspberry Pi Zero W, this innovative tool seamlessly transfers crucial data through the vast network of the Internet of Things (IoT). The acquired results are meticulously compared against data obtained from an incubator analyzer, employing a meticulously designed pre- and post-experimental framework. Examination of the chamber temperature measurement data brings to light a maximum error threshold of 0.009%, corresponding to an error value of 3. Notwithstanding certain persisting measurement discrepancies within the developed module, the study's profound utility is projected to significantly aid medical professionals in their concurrent monitoring of multiple infant incubators, thereby mitigating the impact of these limitations and advancing the realm of neonatal care.

INDEX TERMS Premature infants, Baby incubators, IoT, Temperature, ESP32, Raspberry Pi Zero W

I. Introduction

Births that occur before 38 weeks of pregnancy or with babies weighing less than 2500 grams are considered premature. Births that occur between 38 and 40 weeks of pregnancy and with babies weighing between 2500 and 4000 grams are considered full-term[1][2][3][4][5]. Premature birth is a risk factor for infant mortality[6]because to the vulnerability of premature babies' bodies to harm and their immature organ systems such the lungs, heart, kidneys, liver, and digestive tract[7][8]. Therefore, further precautions must be taken, such as recreating the conditions of the womb in terms of temperature, humidity, and oxygen levels. These are all things that can be provided by a baby incubator, an essential piece of technology that has the potential to save the lives of many prematurely born infants. Baby incubators are used to establish settings that are close to the optimal conditions in the mother's womb and assist physicians in monitoring every element of the child's surroundings. Baby incubators assist in preserving the lives of preterm infants, shield them from hypothermia, and lower newborn death rates[9][10]. Premature babies are protected from hypothermia by being placed in an incubator, which maintains a constant temperature and humidity level. The incubator is kept at a temperature between 32 and 36 degrees Celsius to keep the baby's skin at a healthy 37 degrees Celsius. Furthermore, humidity warms the baby's breath and lets moist air into its lungs. Given that preterm newborns have less fatty tissue and are consequently more susceptible to hypothermia or low body temperature, the needed relative humidity of >70% should be maintained at a level that corresponds to the number of days of incubation[11][12][13]. Relatively low humidity causes preterm newborns' oxygen use and incubator temperature to rise. Higher relative humidity levels, however, are also not recommended for babies since they might promote the development of bacteria and germs[14]. In order to keep temperatures and humidity under control, the incubator must minimize heat loss from the newborns and the environment. The main environmental factors in an incubator are temperature, humidity, oxygen levels, and illumination. It is important to take into account, carefully control the noise in the NICU room, mostly caused by life support machines[15]. Medical staff must keep a close eye on baby incubators in neonatal rooms to make sure the right temperature and humidity levels are maintained. The infant's skin might burn in an incubator that is too hot, and the newborn could become hypothermic if the temperature is too low. There is a substantial risk of illness or death in infants who have heat loss (hypothermia)[16].

Rizky Handayani Rayu and La Ode Saafi (2014) monitored infant incubators as part of their work, "Monitoring Temperature and Humidity in Atmega 328 Microcontroller-Based Incubators." The instrument used in this investigation still transmits data through Bluetooth. Similarly, "Monitoring Baby Incubator," a baby incubator monitoring tool created by Qory Hidayati, Nur Yanti, and Nurwahidah Jamal (2019), also makes use of Bluetooth. Both research use Bluetooth to transmit data. In their study, Furi Kristya Palupi, Sari Luthfiyah, I Dewa Gede Hari Wisana, and Mohseena Thaseen (2021) used a WiFi network to provide a central location for monitoring the temperature and humidity of a newborn incubator. However, this software does little more than record environmental conditions. Deny Alfredo Tampubolon and Nuristadarro developed the "Baby Incubator Monitoring Center via WiFi Network" in 2020, they saw the measured parameters on a Nextion display[17]. The most current research of Raulina Naura Salsabila and Lutfia Nur Fadila (2021) is titled "Monitoring Baby Incubator Through ESP32-Based WiFi Network." Their device detects variables including noise level, humidity, and skin and chamber temperatures. Although WiFi is still used in this investigation to send data, its geographic range is restricted.

Given that a significant percentage of infant incubator monitoring is still done manually, it is clear from the literature search description supplied that midwives or other medical workers must do routine monitoring[18][19]. Therefore, there is a need for an Internet-of-Things-based central baby incubator monitoring tool that can track things like the incubator's internal temperature, baby's skin temperature, humidity, background noise. Results of this instrument may be seen on a computer screen. A website will be used by the monitoring system as a visual application. In order to enhance the quality of future studies, the author has settled on the DS18B20 sensor as the sensor of choice for measuring skin temperature due to its accuracy and reasonable price. The temperature within the chamber of the infant incubator is also measured using a DHT22 sensor, with an average accuracy of 2%. In contrast to the DHT11 humidity sensor, which measures humidity in under 11 milliseconds, the DHT22 humidity sensor has the disadvantage of a longer data transmission time, which is 2 seconds each transmission[20][21][22]. An interconnected network of sensors that may self-configure using established communication protocols is known as the IoT. It allows for the online real-time monitoring, manipulation, analysis, and management of physical factors. IoT ideas are used in this study[23][24][25]. The Raspberry Pi Zero W, a tiny PC module that runs Raspbian, is the supporting device utilized in this investigation.

The development of this tool aims to provide convenience for midwives and other healthcare professionals in monitoring multiple baby incubators. By displaying the monitoring results on a computer screen, medical personnel can easily assess the skin temperature, humidity, noise levels, and overall temperature in the incubator room. This enhanced monitoring capability is crucial in minimizing the occurrence of accidents or adverse events for the patients. With the tool's user-friendly interface and real-time data visualization, healthcare providers can quickly identify any deviations or abnormalities in the monitored parameters. Prompt detection of such issues enables timely interventions and appropriate adjustments to maintain a safe and optimal environment for the infants in the incubators. The tool's implementation leverages the power of IoT technology, enabling seamless connectivity and communication between the monitoring system and the central computer. This facilitates efficient data collection, analysis, and management, empowering healthcare professionals to make informed decisions and ensure the well-being of the infants under their care. Ultimately, the development of this IoT-based Central Baby Incubator Monitoring tool contributes to improved patient safety and enhanced healthcare delivery in the PICU-NICU setting, supporting the dedicated efforts of midwives and healthcare providers in providing the best possible care for premature or critically ill newborns. The primary objective of this study is to develop an autonomous monitoring tool that effectively integrates an ESP32 module and Raspberry Pi Zero W, enabling seamless data transmission via the Internet of Things (IoT) network, and to evaluate its performance by comparing the results with those obtained from an incubator analyzer in a pre- and post-experimental design, aiming to enhance the quality of care provided to infants in need by ensuring precise maintenance of temperature and environmental conditions in incubators. The contribution of the study is :

1. Innovative Monitoring Tool Development: This research contributes to the field by developing an innovative autonomous monitoring tool that combines an ESP32 module and Raspberry Pi Zero W. This tool enables seamless data transfer through the Internet of Things (IoT) network, thereby enhancing the efficiency and effectiveness of monitoring various parameters within infant incubators.
2. Performance Evaluation and Validation. The study contributes by rigorously evaluating the developed monitoring tool's performance through a systematic comparison of its outcomes with those generated by

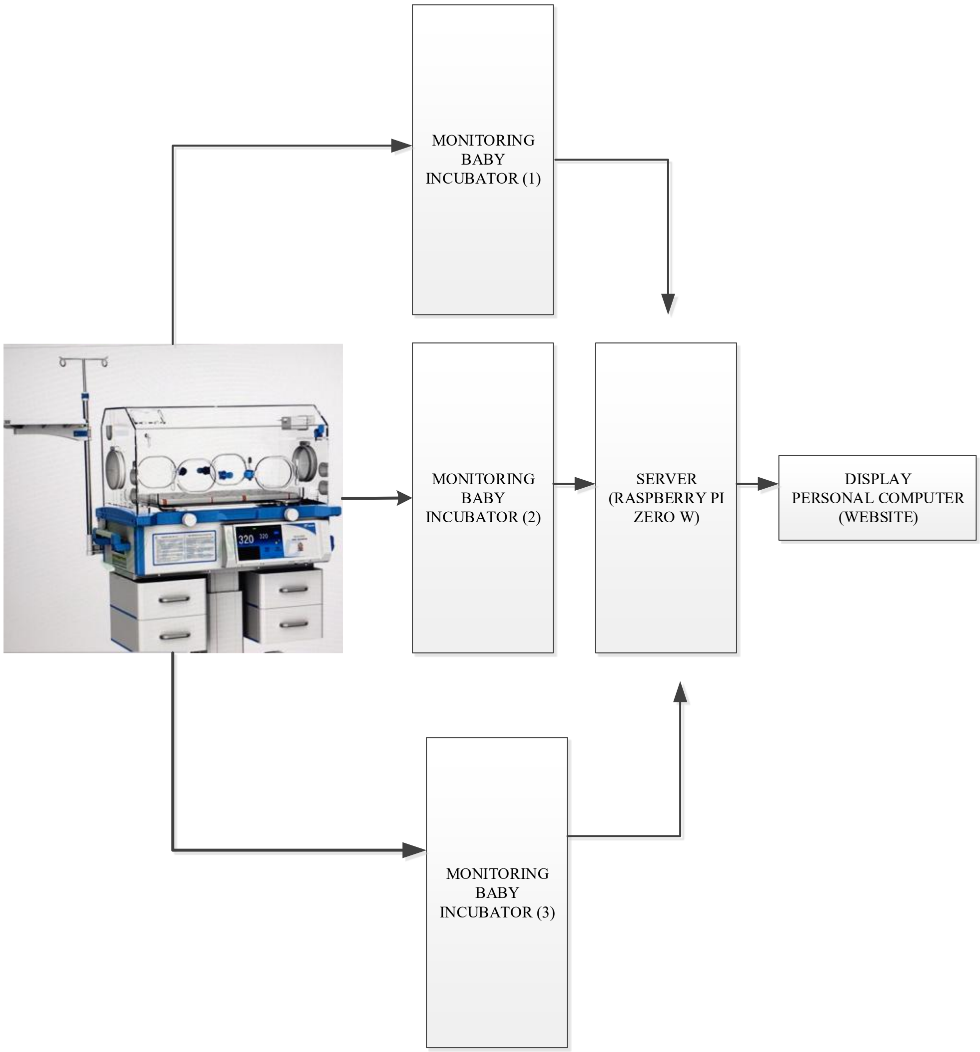

FIGURE 1. System Block Diagram of Baby Incubator Monitoring Research with DHT22 Sensor and DS18B20 Sensor

an established incubator analyzer. By employing a pre- and post-experimental design, this research validates the accuracy and reliability of the monitoring tool in maintaining optimal chamber and skin temperatures within the incubator environment.

3. Advancement of Neonatal Care Practices Through its emphasis on maintaining precise environmental conditions within infant incubators, this research contributes to the improvement of neonatal care practices. By addressing potential challenges and minimizing measurement inaccuracies, this study aids healthcare professionals, such as midwives and medical personnel, in providing higher quality care to vulnerable infants, ultimately promoting their growth and development in a controlled incubator environment.

In FIGURE 1 The infant incubator monitoring system includes a number of sensors, including temperature, skin, humidity, and noise sensors. These sensors can accurately measure the humidity, noise, and temperature of the newborn's surrounding environment, as well as the temperature and body temperature of the infant in the incubator. The ESP32, which acts as the monitoring device, then transmits the acquired data immediately.. Once received, the Raspberry Pi Zero W processes the data and presents the results on the PC display. This system ensures continuous The Raspberry Pi Zero W acts as a central hub, receiving the transmitted data from the sensors monitoring of essential parameters in the baby incubator, providing real-time updates and enabling healthcare professionals to promptly address any deviations or concerns.

II. Method

This investigation was carried out at the Integrated Laboratory and Campus Building of the Department of Electromedical Engineering at Politeknik Kesehatan Kemenkes Surabaya. In this investigation, a before-and-after experimental design was used. For this experiment's monitoring setup, researchers opted for the DS18B20, DHT22, and Analog Sound V2.2 sensors.

The ESP32, which was attached to these sensors, transformed the circuit's output into a digital representation. Additionally, the circuit included a battery that served as a power source for the sensors. The monitoring circuit was also equipped with a charger module, eliminating the need to replace batteries. Data collection involved three baby incubators of the same brand. The process included five repetitions, with measurements taken every 10 minutes once the baby incubator reached a stable temperature condition. The temperature settings studied were 32°C, 34°C, and 36°C. Both the ambient room temperature and the babies' skin temperatures were measured and analyzed. A DHT22 sensor was used to gauge ambient temperature, while a DS18B20 probed the surface of the skin. The Incubator Analyzer, which served as a standard reference for accuracy and calibration, was then used to compare these readings. This comparison made it possible to assess how well the baby incubator maintained the required skin temperature and ambient temperature. This study aimed to assess the accuracy and reliability of infant incubators at various temperature settings.The findings contribute to a better understanding of the performance and effectiveness of the studied infant incubators, providing valuable insights for healthcare professionals and manufacturers in ensuring optimal care for premature infants.

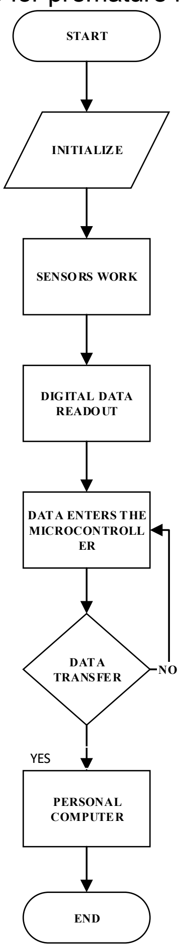

FIGURE 2. The monitor flowchart

In FIGURE 2 Upon pressing the On button, the device will undergo initialization, activating all sensors within each client. The temperature of the baby incubator will all be monitored at the same time by this sensor.The ESP32 monitoring subsystem then receives and processes the gathered data.

The ESP32 will then connect to the server Raspberry Pi Zero W after the data has been processed. In case of a disconnection, the device will continuously attempt to reconnect until both the monitoring and server components are successfully linked. When the connection is established, the monitoring component will transmit the sensor readings to the server for further processing and analysis.

This seamless data transfer and connection between the monitoring and server components ensure real-time monitoring and efficient data management. It enables healthcare professionals to access the sensor readings on the server, facilitating prompt decision-making and timely interventions based on the collected data.

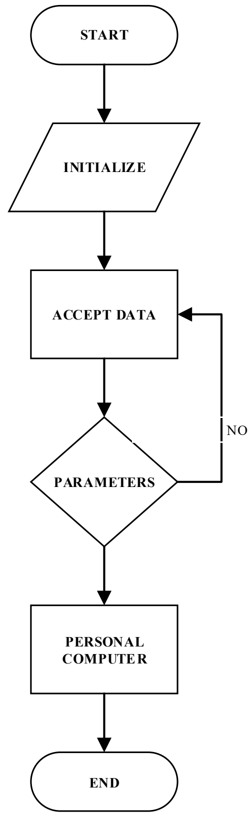

FIGURE 3. The server flowchart

In FIGURE 3 Upon pressing the On button, the system will undergo initialization. All sensors will then start recording data. The microcontroller will analyze the collected information. To facilitate monitoring, the data will be transmitted from the microcontroller to the ESP32, which has been configured as the monitoring component. The ESP32 will then establish a connection with the Raspberry Pi Zero W, acting as the access point server. The data will be processed and managed appropriately by the Raspberry Pi Zero W access point server after it has been received. The attached display will show the parameter data if it is in line with the defined set points.

This monitoring system allows for real-time tracking of important parameters within the baby incubator. It ensures prompt identification of any deviations from the desired conditions, enabling healthcare professionals to take appropriate actions for the well-being of the infants. By leveraging the ESP32 and Raspberry Pi Zero W, the system provides a reliable and efficient means of monitoring and displaying vital information related to the baby incubator's temperature, humidity, and noise levels.

A. Data Analysis

Each variable, such as skin temperature and room temperature, was measured with the newborn incubator set at 32 degrees Celsius, 34 degrees Celsius, and 36 degrees Celsius. To assure precision and dependability, each measurement was carried out five times.

Eq.(1) was used to find the mean or average in order to compute the average measurement value. By adding up all the values and dividing the result by the total number of data points in the collection, one may get the average. Using this statistical technique, it is possible to fully comprehend the general trend and central tendency of the recorded temperatures across a number of trials.

By calculating the average measurement value, we can gain insights into the typical behavior of the chamber temperature and skin temperature under different settings. This information is valuable for evaluating the performance of the baby incubator and assessing its ability to maintain stable and desired temperature levels.

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

The%error serves as a representation of system error and shows how much the design or model deviates from the norm. A smaller average difference between each data point is shown by a lower%error value. The error procedure shown by Eq.(2) is used to determine the error percentage:

$$\%\text{ERROR} = \frac{(x_n - \text{x})}{x_n} \times 100\% \quad (2)$$

The measured value of the machine calibrator is denoted by "xn" in the equation, while the measured value of the module under evaluation is denoted by "x". Using this method, we may quantify the amount of discrepancy between the module's measured values and the machine calibrator. The %error value allows us to gauge the accuracy and precision of the module's measurements in comparison to the established standard.

III. Result

The research conducted involved thorough testing of the module using the Incubator Analyzer comparison tool. FIGURE 4 represents a comprehensive monitoring module comprising an ESP32, DS18B20 Sensor, DHT22 Sensor, and Analog Sound V2.2. This module plays a crucial role in ensuring efficient monitoring of various parameters in a baby incubator. Additionally, it incorporates a battery circuit and utilizes a Lithium Battery as the power supply, which facilitates the operation of the voltage up module. The inclusion of a Lithium Battery not only enhances the module's portability but also contributes to its reliable performance. Furthermore, FIGURE 5 showcases a user-friendly display of the baby incubator monitoring system, accessible through a dedicated website. This display provides real-time updates and enables healthcare professionals and caregivers to conveniently monitor and assess the incubator's crucial metrics. The integration of these advanced technologies and features underscores the significance of this research in advancing the field of baby incubation and improving the overall quality of care provided to infants in need.

FIGURE 4. Design of monitoring module

The TABLE 1 Average chamber temperatures determined by averaging readings from the thermometer are shown above. After waiting for the temperature in three different newborn incubators set at 32 degrees Celsius, 34 degrees Celsius, and 36 degrees Celsius to settle, measurements were taken to ascertain the average chamber temperature values. The average temperatures in the chambers were calculated using data from three separate modules.

The table below displays the average temperatures measured inside the chamber. For each temperature condition, data was collected five times and then compared in real time using the Incu Analyzer. Module 1 averaged 31.2 degrees Celsius, whereas module 3 averaged 31 degrees Celsius, and module 2 averaged 29.8 degrees Celsius when the Incu Analyzer was set to 32 degrees Celsius. The results were 33.2°C for Module 1, 33.1°C for Module 2, and 32.8°C for Module 3 at a setting of 34°C. The readings were 35°C for module 1, 34.9°C for module 2, and 34.4°C for module 3 at a setting of 36°C.

TABLE 1
Average Overall Chamber Temperature Measurement

Setting	Incu 1	Incu 2	Incu 3	Modul 1	Modul 2	Modul 3	Error 1	Error 2	Error 3
32°C	31.2	30.8	30.1	31.2	31	29.8	0.001	-0.006	0.009
34°C	33.3	33	34.1	33.2	33.1	32.8	0.002	-0.001	0.001
36°C	35.1	34.7	34.1	35	34.9	34.4	0.001	-0.004	0.008

TABLE 2
Overall Average Results of Skin Temperature Measurements

Setting	INCU I	INCU II	INCU III	MODUL 1	MODUL 2	MODUL 3	Error 1	Error 2	Error 3
32°C	31.8	30	30	31.8	30.5	30.3	0.0006	-0.01	0.01
34°C	34°C	33.7	33.4	34	33.7	33.8	0.0005	-0.0005	0.01
36°C	36°C	34.6	34.4	35.9	34.6	34.9	0.001	-0.002	0.01

FIGURE 5. Display screen

The measurements showed that at 32 degrees Celsius, the highest discrepancy was found between module 3 and the Incu Analyzer data. All modules showed the same difference value when measured with the Incu Analyzer at 34 degrees Celsius, whereas at 36 degrees Celsius, the difference was greatest for module 3.

For each temperature setting and monitoring, the measurement data included error values. At 32 degrees Celsius, error rates of 0.001%, 0.006%, and 0.009% were recorded by Monitors 1, 2, and 3, respectively. At 34 degrees Celsius, the error values for Monitoring 1 were 0.002%, Monitoring 2 was -0.001%, and Monitoring 3 was also -0.001%. Lastly, at a setting of 36°C, monitoring 1 had an error value of 0.001%, monitoring 2 had -0.004%, and monitoring 3 had 0.008%. Monitor 3 reported an error of 0.009% at 32 degrees Celsius, Monitor 1 recorded an error of 0.002% at 34 degrees Celsius, and Monitor 3 recorded an error of 0.008% at 36 degrees Celsius.

Errors were below an acceptable level, although they were noticeable when compared to the Incu Analyzer because of the use of less accurate newborn incubators and slight delays in temperature changes. The alternating data transmission between parameter measurements and data buildup on the server contributed to the slightly delayed and non-real-time temperature changes observed during the data collection process.

The TABLE 2 The average skin temperature readings estimated from the data collected using the measuring equipment are shown above. The average chamber temperature represents three infant incubators set at 32°C, 34°C, and 36°C. As soon as the temperature was stabilized, measurements were taken. The method required averaging the results of three separate temperature measurements taken within the chamber.

Data collection was performed five times for each temperature setting, and the results were compared in real time using the Incu Analyzer comparison tool to produce the average chamber temperature values given in the table above. Incu Analyzer averages for 32 degrees Celsius showed 31.8 degrees, 30.5 degrees, and 30.3 degrees for modules 1, 2, and 3, respectively. At 34 degrees Celsius, Module 1 registered 34 degrees, Module 2 33.7 degrees, and Module 3 33.8 degrees. Finally, at a setting of 36°C, the values were 35.9°C for module 1, 34.6°C for module 2, and 34.9°C for module 3. Module 2 showed the greatest deviation from the Incu Analyzer data at 32 degrees Celsius, while Module 3 showed the greatest deviation at 34 and 36 degrees Celsius.

For each temperature setting and monitoring, the measurement data included error values. At 32 degrees Celsius, the errors for Monitors 1 and 2 were 0.0006 and 0.01, while those for Monitor 3 were 0.01. Error values ranged from 0.0005% for monitoring 1, to -0.0005% for monitoring 2, and to -0.01% for monitoring 3 when the temperature was adjusted to 34 degrees Celsius. Lastly, at a setting of 36°C, monitoring 1 had an error value of 0.001%, monitoring 2 had -

0.002%, and monitoring 3 had 0.01%. The largest error values were -0.01% for monitoring 3 at a setting of 36°C, 0.01% for display three at a temperature 34°C, and 0.01% for monitoring 3 at a temperature setting of 32°C.

Despite the relatively high differences between the Incu Analyzer readings and the measurements obtained from the baby incubator used in the data collection process, the errors remained within an acceptable threshold. It is worth noting that the temperature changes experienced slight delays and were not entirely real-time due to the alternating data transmission between parameter measurements and the buildup of data received by the server.

IV. Discussion

Previous research has explored the development of monitoring devices for baby incubators using various sensor types and delivery methods. However, many of these methods rely on PCs and routers, and the error rates in previous studies have remained relatively high. To overcome the limitations identified in previous research, our study aims to create an innovative monitoring tool for measuring room temperature and skin temperature in baby incubators by harnessing the power of the Internet of Things (IoT) network.

During our measurements using the monitoring module and comparing them with the incubator analyzer, we observed some errors. It is worth noting that these errors fall within an acceptable threshold. While there was a discrepancy between the measured results and the expected values, this can be attributed to minor delays in temperature changes and the non-real-time nature of the data. These delays arise due to the volume of data being transmitted, as the module switches between sending data for parameter measurements and receiving the data buildup on the server.

Our research represents a significant advancement in the field, building upon previous studies and addressing the pressing need for a streamlined and efficient monitoring tool for baby incubators. By leveraging IoT technology, our objective is to enhance the accuracy and real-time nature of temperature measurements, ultimately improving the quality of care provided to infants in need. weaknesses and limitations of this study are as follow:

1. While the study focuses on maintaining ideal temperatures within infant incubators, other crucial environmental factors such as humidity and oxygen concentrations, which also influence infant development, are not comprehensively addressed. This limitation might affect the holistic applicability of the developed monitoring tool.
2. Although the monitoring tool is designed to be compatible with various types of infant incubators, variations in design and functionality across different incubator models could potentially impact the tool's effectiveness and data accuracy. This issue could limit the tool's generalizability across diverse healthcare settings.
3. The measurement accuracy of temperature sensors (DHT22 and DS18B20) plays a pivotal role in the reliability of the monitoring tool. Any inherent inaccuracies or deviations in sensor readings might lead to skewed results and compromise the tool's overall performance.
4. The study's validation process, involving a comparison with an incubator analyzer, might not account for all potential scenarios and conditions that healthcare practitioners encounter. Variations in real-world usage, such as changes in incubator load or positioning, could introduce uncertainties not fully explored in the experimental design.
5. The research might lack a longitudinal approach, which could provide insights into the monitoring tool's stability and performance over extended periods. Long-term usage patterns and potential issues that emerge over time might not be adequately addressed within the scope of the current study.
6. Despite efforts to minimize measurement errors, inherent inaccuracies in sensor readings and system performance could still persist. These errors might be particularly pronounced in critical situations and could undermine the tool's precision during real-time monitoring.
7. While the study emphasizes the potential benefits of the monitoring tool on neonatal care, it might fall short in providing an in-depth assessment of the actual clinical impact on patient outcomes. Evaluating how the tool affects medical decision-making and patient well-being remains an area that could be explored further.

The implications of this study are multi-faceted and hold promising potential to advance neonatal care practices, technological innovation, and healthcare efficiency. Firstly, the development of an autonomous monitoring tool that seamlessly integrates an ESP32 module and Raspberry Pi Zero W offers a transformative solution for enhancing the quality of care provided to vulnerable infants. By maintaining precise temperature conditions within infant incubators, this tool addresses a crucial aspect of neonatal care, minimizing the risk of temperature-related complications and creating an environment conducive to optimal growth and development.

Furthermore, the study's rigorous performance evaluation through a comparative analysis with an established incubator analyzer contributes to the realm of medical technology validation. This not only underscores the reliability of the monitoring tool but also establishes a framework for assessing the accuracy of similar IoT-based systems in medical contexts. As healthcare increasingly incorporates advanced technology, the study's approach sets a precedent for ensuring the effectiveness of such tools in real-world settings.

In terms of healthcare practice, the implications are profound. Healthcare professionals, particularly midwives and medical personnel responsible for monitoring multiple infant incubators, stand to benefit significantly from the study's findings. The developed tool has the potential to alleviate their workload, enhance monitoring precision, and enable timely interventions, ultimately fostering better outcomes for infants in need. Moreover, as the tool is designed to be compatible with various infant incubator models, its applicability extends to diverse healthcare settings, contributing to standardization and improved care delivery across different institutions. The study also has implications for future research and innovation. It highlights the necessity of exploring a holistic approach to infant incubator technology that considers not only temperature control but also other critical environmental factors. This opens avenues for interdisciplinary collaborations between medical professionals, engineers, and researchers to create comprehensive solutions that cater to the complex needs of neonatal care.

In conclusion, this study's implications are far-reaching, encompassing advancements in neonatal care, medical technology validation, healthcare practice, and interdisciplinary collaboration. By addressing limitations, fine-tuning the monitoring tool, and fostering a culture of innovation, the study sets the stage for improved care for infants in need, shaping the landscape of neonatal healthcare for years to come.

IV. Conclusion

We set out with the central aim of this study being the enhancement of midwives' and medical personnel's capabilities through an adept tool designed to remotely monitor multiple infant incubators. The garnered results stemming from the measurement data underscored the precision of this monitoring system. Regarding chamber temperature measurements, varying temperature settings revealed distinct peak error values. At 32°C, monitoring iteration 3 manifested an error rate of 0.009%; at 34°C, monitoring iteration 1 displayed an error rate of 0.002%. Similarly, at 36°C, monitoring iteration 3 showcased an error rate of 0.008%. These findings collectively underscore the consistent and dependable nature of the monitoring tool, consistently delivering accurate temperature measurements that align with acceptable error parameters. Regarding skin temperature measurements, specific temperature settings also saw prominent error values. At 32°C, both monitoring iteration 2 and 3 exhibited an error rate of 0.01%. At 34°C, monitoring iteration 3 revealed an error rate of 0.01%, and at 36°C, monitoring iteration 3 demonstrated an error rate of -0.01%. Despite these deviations, they remained well within the acceptable threshold, thus affirming the reliability of the skin temperature measurements provided. Our aspiration is that this study's outcomes bear substantial significance in augmenting the services offered by midwives and healthcare professionals. Through the provisioning of a streamlined monitoring system for infant incubators, the expedient identification and resolution of potential issues become viable, ultimately translating to improved outcomes for the infants entrusted to their care. The insights derived from this research stand to preempt undesirable occurrences, culminating in an elevated standard of care extended to the deserving neonates requiring such attention.

References

[1] M. Suruthi and S. Suma, "Microcontroller Based Baby Incubator Using Sensors | Semantic Scholar," pp. 12037–12044, 2015, doi: 10.15680/IJIRSET.2015.0412050.

[2] F. Kristya, S. Luthfiyah, I. D. G. Hari Wisana, and M. Thaseen, "Baby Incubator Monitoring Center for Temperature and Humidity using WiFi Network," *J. Electron. Electromed. Eng. Med. Informatics*, vol. 3, no. 1, pp. 8–13, 2021, doi: 10.35882/jeeemi.v3i1.2.

[3] M. Shaib, M. Rashid, L. Hamawy, M. Arnout, I. El Majzoub, and A. J. Zaylaa, "Advanced portable preterm baby incubator," *Int. Conf. Adv. Biomed. Eng. ICABME*, vol. 2017-Octob, no. October, 2017, doi: 10.1109/ICABME.2017.8167522.

[4] H. B. D. L. Mathew, Ashish Gupta, "Controlling of Temperature and Humidity for an Infant Incubator Using Microcontroller," *Int. J. Adv. Res. Electr. Electron. Instrum. Eng.*, vol. 04, no. 06, pp. 4975–4982, 2015, doi: 10.15662/ijareeie.2015.0406012.

[5] H. Mittal, L. Mathew, and A. Gupta, "Design and Development of an Infant Incubator for Controlling Multiple Parameters," *Int. J. Emerg. Trends Electr. Electron.*, vol. 11, no. 5, pp. 2320–9569, 2015.

[6] M. V. Narayana, K. Dusarlapudi, K. Uday Kiran, and B. Sakthi Kumar, "IoT based real time neonate monitoring system using arduino," *J. Adv. Res. Dyn. Control Syst.*, vol. 9, no. Special issue 14, pp. 1764–1772, 2017.

[7] L. Doukkali, F. Z. laamiri, N. B. Mechita, L. Lahlou, M. Habibi, and A. Barkat, "The Issue of Care Given to Premature Infants in the Provincial Hospital Center of Missour," *J. Biosci. Med.*, vol. 04, no. 05, pp. 76–88, 2016, doi: 10.4236/jbm.2016.45008.

[8] P. C. Nugraha, M. R. Mak'ruf, Lusiana, and S. Luthfiyah, "Long Distance Dual SpO2 Monitoring in Premature Babies Via Bluetooth Communication," *J. Electron. Electromed. Eng. Med. Informatics*, vol. 3, no. 2, pp. 106–110, 2021, doi: 10.35882/jeeemi.v3i2.7.

[9] T. A. Tisa, Z. A. Nisha, and M. A. Kiber, "Design of an Enhanced Temperature Control System for Neonatal Incubator," *Bangladesh J. Med. Phys.*, vol. 5, no. 1, pp. 53–61, 2013, doi: 10.3329/bjmp.v5i1.14668.

[10] M. Ali, M. Abdelwahab, S. Awadekreim, and S. Abdalla, "Development of a Monitoring and Control System of Infant Incubator," *2018 Int. Conf. Comput. Control. Electr. Electron. Eng. ICCCEEE 2018*, no. Lcd, pp. 1–4, 2018, doi: 10.1109/ICCCEEE.2018.8515785.

[11] M. Bogdan, "How to Use the DHT22 Sensor for Measuring Temperature and Humidity with the Arduino Board," *ACTA Univ. Cibiniensis*, vol. 68, no. 1, pp. 22–25, 2016, doi: 10.1515/aucts-2016-0005.

[12] L. Nachabe, M. Girod-Genet, B. ElHassan, and J. Jammas, "M-health application for neonatal incubator signals monitoring through a CoAP-based multi-agent system," *2015 Int. Conf. Adv. Biomed. Eng. ICABME 2015*, no. September, pp. 170–173, 2015, doi: 10.1109/ICABME.2015.7323279.

[13] R. A. Koestoer, N. Pancasaputra, I. Roihan, and Harinaldi, "A

simple calibration methods of relative humidity sensor DHT22 for tropical climates based on Arduino data acquisition system," *AIP Conf. Proc.*, vol. 2062, no. January, 2019, doi: 10.1063/1.5086556.

[14] Syarifatul Ainiyah, D. H. Andayani, A. Pundji, and M. Shaib, "Development of Incubator Analyzer Based on Computer with Temperature And Humidity Parameters," *J. Electron. Electromed. Eng. Med. Informatics*, vol. 2, no. 2, pp. 48–57, 2020, doi: 10.35882/jeeemi.v2i2.3.

[15] I. M. S. Wibawa and I. K. Putra, "Design of air temperature and humidity measurement based on Arduino ATmega 328P with DHT22 sensor," *Int. J. Phys. Sci. Eng.*, vol. 6, no. 1, pp. 9–17, 2022, doi: 10.53730/ijpse.v6n1.3065.

[16] D. D. Vyas, "System for Remote Monitoring and Control of Baby Incubator and Warmer," no. May 2016, pp. 2–8, 2017.

[17] Lamidi, T. Hamzah, Triwiyanto, Nuristadarro, and D. E. Tampubolon, "Baby Incubator Monitoring Center Using Wi-Fi Network for Data Transmission," *J. Biomimetics, Biomater. Biomed. Eng.*, vol. 55, pp. 275–287, 2022, doi: 10.4028/p-392j82.

[18] A. Rajalakshmi, K. A. Sunitha, and R. Venkataraman, "A survey on neonatal incubator monitoring system," *J. Phys. Conf. Ser.*, vol. 1362, no. 1, 2019, doi: 10.1088/1742-6596/1362/1/012128.

[19] I. Allafi and T. Iqbal, "Design and implementation of a low cost web server using ESP32 for real-time photovoltaic system monitoring," *2017 IEEE Electr. Power Energy Conf. EPEC 2017*, vol. 2017-Octob, pp. 1–5, 2018, doi: 10.1109/EPEC.2017.8286184.

[20] D. P. Ramya and M. A. Hussain, "A light weight secured and efficient health monitoring system implemented over IOT based networks," *Int. J. Innov. Technol. Explor. Eng.*, vol. 8, no. 6, pp. 1806–1809, 2019.

[21] J. Islam *et al.*, "Design and Development of Microcontroller Based Wireless Humidity Monitor," *IOSR J. Electr. Electron. Eng.*, vol. 13, no. 2, pp. 41–46, 2018, doi: 10.9790/1676-1302034146.

[22] M. Hulea, G. Mois, S. Folea, L. Miclea, and V. Biscu, "Wi-sensors: A low power Wi-Fi solution for temperature and humidity measurement," *IECON Proc. (Industrial Electron. Conf.*, pp. 4011–4015, 2013, doi: 10.1109/IECON.2013.6699777.

[23] G. D. Kumar, "Realization Of A Low Cost Smart Home System Using Telegram Messenger And Voice," *Int. J. Pure Appl. Math.*, vol. 116, no. 5, pp. 85–90, 2017, [Online]. Available: http://acadpubl.eu/jsi/2017-116-5-7/articles/5/15.pdf.

[24] N. Suresh, I. Behera, P. Bhagat, and P. Thakur, "Early Flood Monitoring System using IoT Applictions," *Int. Res. J. Eng. Technol.*, vol. 07, no. 05, pp. 3348–3353, 2020, [Online]. Available: https://www.irjet.net/archives/V7/i5/IRJET-V7I5642.pdf.

[25] F. Aktas, E. Kavus, and Y. Kavus, "A real-time infant health monitoring system for hard of hearing parents by using android-based mobil devices," *Istanbul Univ. - J. Electr. Electron. Eng.*, vol. 17, no. March, pp. 3107–3112, 2017.