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An Android INCU Analyzer Design to Calibrate Infant Incubator Using Bluetooth Communication for Real-Time and Wireless Monitoring

Vijay Anant Athavale[1], Abhilash Pati[2], A K M Bellal Hossain[3], Sari Luthfiyah[4,#], Triwiyanto[4]

[1] Walchand Institute of Technology, Solapur, INDIA (email: vijay.athavale@gmail.com)
[2] Siksha 'O' Anusandhan Deemed to be University, Bhubaneswar, INDIA (email: er.abhilash.pati@gmail.com)
[3] University of Bisha, SAUDI ARABIA (email: bellalcs@gmail.com)
[4] Department of Medical Electronics Technology, Poltekkes Kemenkes Surabaya, INDONESIA

[#]Corresponding author: Sari Luthfiyah (email: sariluth@poltekkesdepkes-sby.ac.id)

ABSTRACT Worldwide, over 4 million babies die within a month of birth each year. Of these, 3.9 million are in developing countries. A proportion approximately 25% of these deaths are due to complications of premature birth, most commonly inadequate thermoregulation, water loss, and neonatal jaundice. An infant incubator provides stable temperature, relative humidity, and airflow values. A periodical calibration should be applied on infant incubator to monitor the functionality. The study aims to develop a calibration device that measures temperature, humidity, airflow, and noise in the baby incubator based on an Android application with Bluetooth communication to improve the calibration monitoring process. This is to achieve a better performance of the conventional INCU analyzer. The contribution of this research is that the values of the temperature, humidity, airflow, and noise can be displayed on both devices, the INCU analyzer machine, and mobile phone; thus, the user can monitor the measurement activities wirelessly. Furthermore, the statistical calculation for all measurements can be saved on a mobile phone device. The main design consists of temperature sensor LM35, humidity sensor DHT22, airflow sensor MPX5010DP, an analog signal conditioning circuit, an Arduino Mega microcontroller, Bluetooth module HC05, and Android mobile phone. The resulting design was compared to the standard or calibrator INCU analyzer machine (Fluke Biomedical INCU II). This study found that the smallest error is -1.72%°C, -0.106 % RH, -1.727% dB, and <0.1% m/s for temperature, humidity, noise, and airflow parameters, respectively. After the evaluation process, this device can be used as an INCU analyzer to calibrate the infant incubator.

INDEX TERMS Incubator Analyzer, Temperature, Noise, Android, Bluetooth communication

I. INTRODUCTION

Every year, about one million babies die in developing countries due to premature birth. Premature babies are born before their organs are mature enough to allow average survival after delivery. Because premature babies are at risk of oxygen deprivation, hypothermia, and many other adverse conditions, they need special care and attention [1][2]. One of the main problems faced by newborns is inadequate thermoregulation. The temperature in the womb is 38^{0}C [3]. If heat loss is not prevented and continues, the baby develops hypothermia and is at increased risk of developing health problems and dying [4]. Therefore, an incubator is required to provide the environment necessary for the baby's survival. An incubator analyzer is a calibration tool that measures the temperature, humidity, noise level, and airflow conditions in the baby incubator to ensure that all parameters of the baby incubator are suitable for the newborn [4]. Several studies have developed an incubator analyzer that also sends data via Bluetooth that is displayed through a personal computer [5]-[7]. However, there is no data storage, so the operator cannot see the results of previous measurements. According to tests and measurements, the enormous error value at a distance of 5 meters on the temperature sensor module is 0.672% at T1, 0.757% at T2, 0.806% at T3, and 0.787% at T4. The airflow sensor module detects an airflow velocity of at least 0.2 m/s when the anemometer is rotating. The error value of the humidity sensor is -1.03% at a measurement distance of 10 cm, -0.95% at a distance of 2 meters, and 1.12% at a distance of 5 meters [8]. The error value of the noise sensor is -0.17% at a distance of 10 cm, 0.04% at a distance of 2 meters, and 0.35% at a distance of 5 meters. Moreover, it was newly developed by other researchers where this tool already uses the Android display [9]-[11]. However, there is a drawback that there is no data storage so that the operator cannot see the results of previous measurements. Measuring the effective distance Bluetooth sensor noise has an average error of 0.44% with a measurement distance of 10 m [12]. The biggest error is in the 37ºC temperature setting with the module temperature sensor: 0.286% for the T1 sensor, 1.679% for the T2 sensor, 6.374% for the T3 sensor, 2.187% for the T4 sensor, 1.242% for the T5, and 2.700% for the T6. The airflow sensor can detect airflow of at least 0.2 m/s when the baby incubator is turned on. The effective distance of the receiver and transmitter used is 50 cm. Then the last one was developed by Azkiyak et al. and other studies; this device is already portable using an Android display and is equipped with storage. However, there are still shortcomings, namely errors that still exceed 5% [13]-[17]. The biggest error on the DS18B20 sensor is 4.33325%, while the biggest error on the K-type Thermocouple temperature sensor is 7.3138%. The biggest error on the analog sound sensor V2 noise sensor is 8.8403%.

The results of temperature and noise errors in the last development are still more than 5%. To improve the performance of the incubator analyzer by replacing the DS18B20 sensor with LM35 because LM35 has an analog voltage output so that an appropriate amplification can be used to get better performance than the previous tool, as well as create a noise sensor circuit with better performance than the previous design. Furthermore, continuous Android application monitoring is an added value for the INCU analyzer. Therefore, this research aims to develop an INCU analyzer-based Android application that can monitor all of the infant incubator machine parameters.

II. MATERIALS AND METHODS

The study is conducted as experimental research. The authors proposed an Android INCU analyzer to measure the infant incubator parameters in this study. The materials and method will be explained in the following section.

A. DATA COLLECTION

In this study, the researchers compared the design (INCU analyzer based on Android application) and the standard INCU analyzer (the Fluke Biomedical INCU II) as a comparison device. This study uses the LM35 sensor as a temperature sensor, mic condenser as a noise sensor, DHT22 as humidity sensor, MPX5010DP as airflow sensor, Arduino Mega component as a microcontroller, and HC-05 as data transmission to Android mobile phone [18]. An open-source Android application based (MIT app inventor) was used [19][20].

In the measurement stage, the incubator baby machine was set at 37oC. In order to obtain a normal distribution for the temperature and humidity, the user should wait for 30 to 60 minutes before the model was placed inside the incubator baby. After the incubator baby's temperature is stable, then the incubator monitoring module is placed in the middle of the baby incubator box. The temperature sensors T1, T2, T3, T4, T5, and TM (temperature on the mattress) were placed at a predetermined point (FIGURE 1). Further, the humidity, flow, and noise sensor were placed the certain location in the incubator chamber. After the proposed design is placed in the baby incubator box, the next step is to turn on the INCU monitoring system [21][22]. After this step, the measurement parameter values can be read directly on the INCU monitor module on the liquid crystal display (LCD) screen. Monitoring the INCU parameters on the mobile phone screen is applied by running the INCU analyzer program application (APK, an Android application) program that has been installed and configured. The communication is started by activating the Bluetooth communication between the INCU monitoring system and the mobile phone. The user should select the HC-05 in the provided Bluetooth list on the mobile phone screen. After the communication is established then the data communication will continue. Furthermore, the measured parameter will be displayed on the mobile phone screen. Moreover, if the user would like to save the data, then the user should press the START button. The STOP button was used to finish the data collection process.

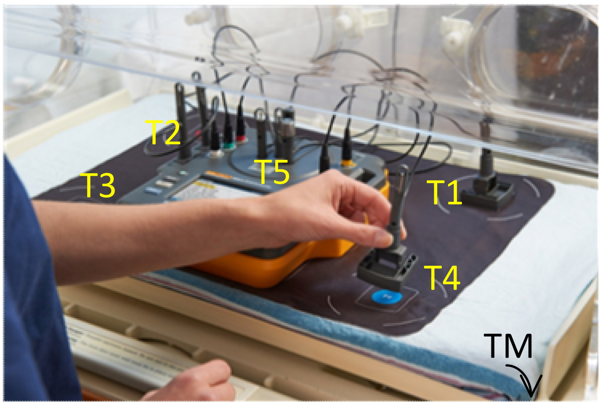

FIGURE 1. Temperature measurement location at T1, T2, T3, T4, T5 and TM used standard incubator analyzer INCU II.

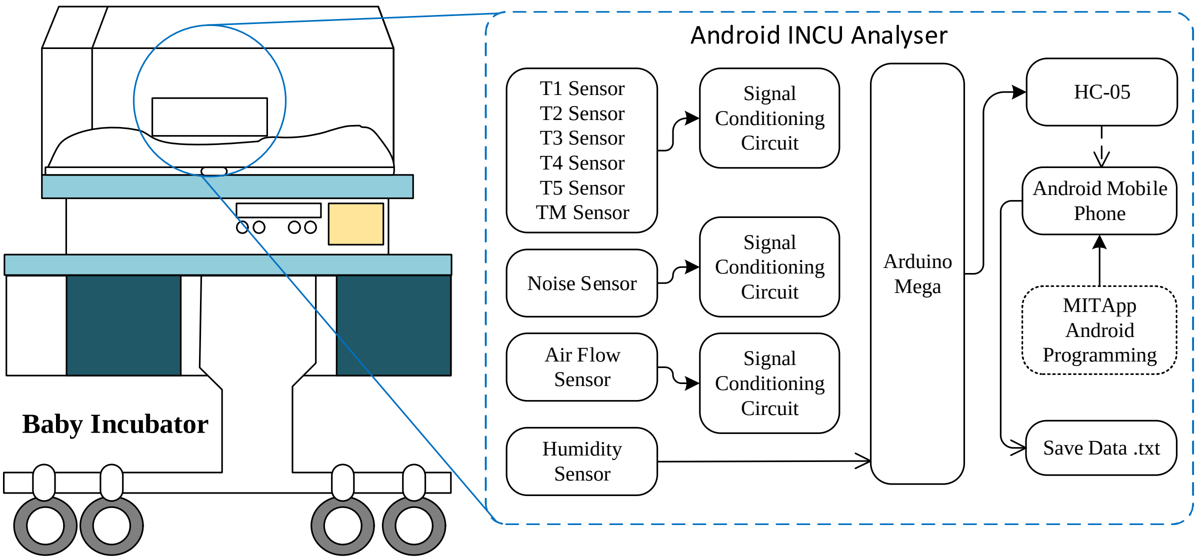

FIGURE 2. The proposed design Android INCU analyzer using MIT App Inventor application to monitor temperature, noise, airflow and humidity sensor wirelessly using Bluetooth connection to Android mobile phone. The system was controlled by using the Arduino MEGA and HC-05 Bluetooth module as the media communication between the system and Android mobile phone application.

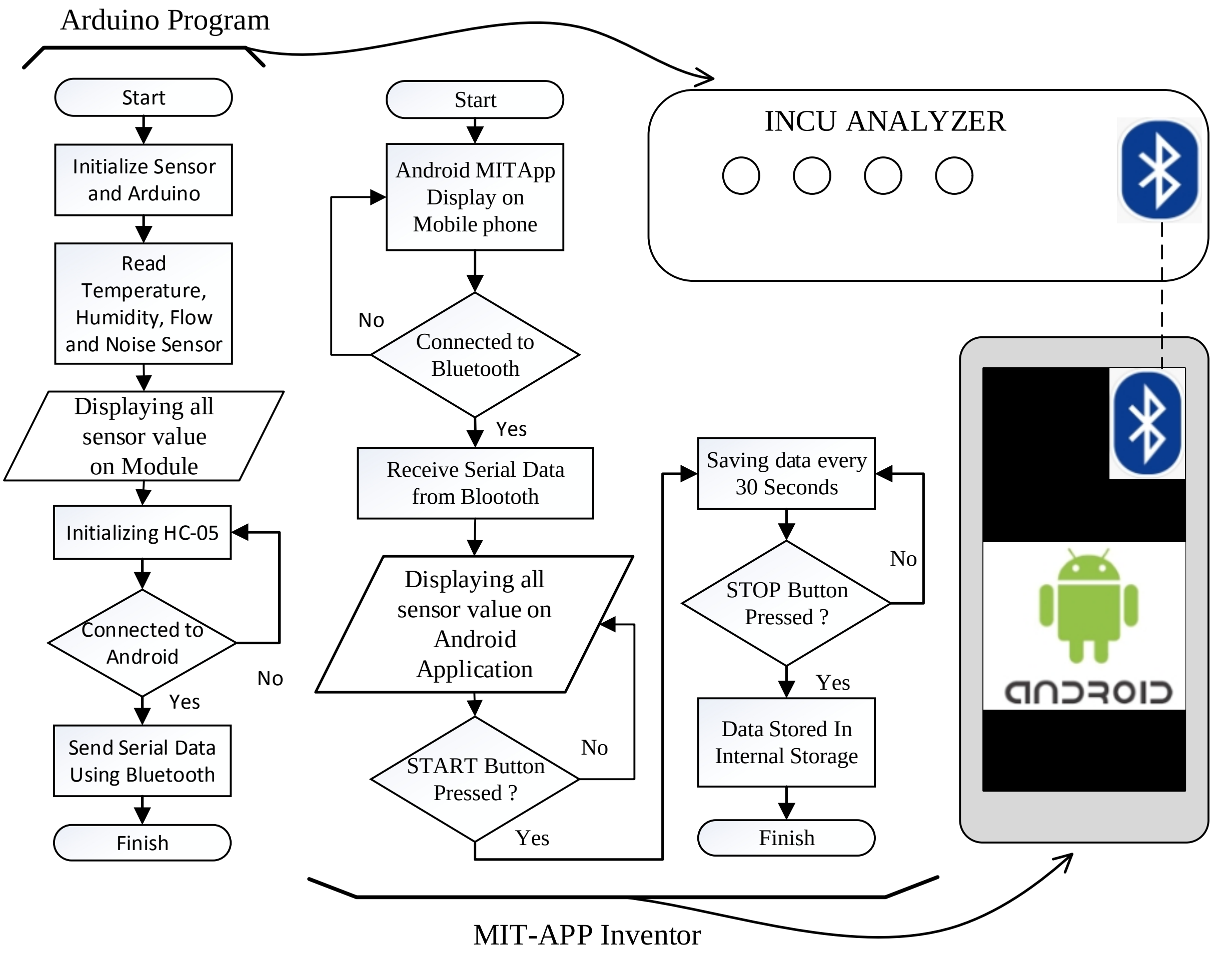

FIGURE 3. The flowchart of the system to detect the physical parameter (temperature, noise, airflow and humidity sensor) and send measured parameters to Android mobile phone. The left part was the flowchart for Arduino programme to detect the parameters and the right part was the flowchart to design the Android application using Android MIT app inventor.

FIGURE 2 shows a block diagram of the entire system. A small box inside the incubator chamber represents the proposed design, namely the Android INCU analyzer. With measurement parameters T1, T2, T3, T4, T5 and TM. Furthermore, other parameters, such as humidity, noise and airflow are also measured. FIGURE 3 shows two flowcharts. The flowchart on the left shows the software design for the Arduino Mega microcontroller, while the flowchart on the right shows the software design for the Android application

B. DATA ANALYSIS

Measurements of each parameter, temperature, humidity, flow, and noise, all were repeated 20 times. The average value of the measurement is obtained by using the mean or average by applying equation (1).:

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

where $\bar{x}$ indicates the mean (average) value for n-measurement, x1 indicates the first measurement, x2 shows the second measurement, and xn indicates the n measurement. The standard deviation is a value that indicates the level (degree) of variation in a group of data or a standard measure of deviation from its mean. The standard deviation (SD) formula can be shown in equation (2):

$$\mathrm{SD} = \sqrt{\frac{\Sigma(x-\bar{x})^2}{(n-1)}} \quad (2)$$

where xi indicates the amount of the desired values, x indicates the average of the measurement results, n shows the number of measurements. Uncertainty (UA) is doubt that appears in each measurement result. The uncertainty formula is shown in equation (3):

$$\boldsymbol{U} = \frac{\boldsymbol{s}}{\sqrt{\boldsymbol{n}}} \quad (3)$$

where UA indicates the uncertainty value from the total measurement, SD shows the resulted standard deviation, and n shows the amount of measurement. the %error shows the error of the system. The lower value Error is the difference between the mean of each data. The error can show the deviation between the standard and the design or model. The error formula is shown in equation (4).

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

where xn is the value measured from the calibrator machine. The x is the value measured from the design.

III. RESULT

We found that the error values range between -0.1% and 1.5% based on the temperature measurement. The detailed measurement results are shown in the following table and graphics. The measurement was conducted 20 times for each parameter (temperature T1, T2, T3, T4, T5, TM, humidity, airflow, and noise). The INCU II (standard INCU analyzer) was used as a comparison device in this study. TABLE 1 and FIGURE 4 show the average measurement results on the design and standard INCU analyzer. We found the difference between the calibrator and design result when the noise was measured in these two devices. The temperature paremeter measurement error between the calibrator (INCU 2) and the design for the difference setpoint is shown in TABLE 2 and FIGURE 5. In the temperature measurement, the smallest error value is 0.0373% at T1, the setting temperature is 36ºC, and the largest error is 2.617% at T4, the setting temperature is 35ºC. In the noise parameter, the smallest error value is -1.727% at 37ºC settings, and the largest error is 5.254% at 36ºC settings.

TABLE 1
The comparison measurement between the design and calibrator unit for three setpoint (35, 36, and 37) in the five certain location T1, T2, T3, T4, T5 and TM. All of the measurement parameters were performed 20 times for each setpoint. A DC fan was introduced to study interference due to noise in the system (for the proposed design and calibrator unit).

Measuring Point		Mean			
		35ºC	36 ºC	37 ºC	with DC Fan(dB)
Design	T1	34.3917	35.6417	36.3833	-
	T2	34.3208	35.5708	36.3333	-
	T3	34.275	35.4833	36.1958	-
	T4	34.8625	35.9333	36.6917	-
	T5	35.1417	36.7125	37.275	-
	TM	33.0792	34.2625	34.6042	-
	Noise	45.86	48.32	47.5067	69.5667
Calibrator	T1	34.2933	35.655	36.0633	-
	T2	34.0767	35.41	36.015	-
	T3	34.295	35.6133	36.1083	-
	T4	33.9733	35.2067	35.7767	-
	T5	35.1217	36.9867	36.9317	-
	TM	33.15	34.5583	34.55	-
	Noise	47.3667	51	46.7	67.7333

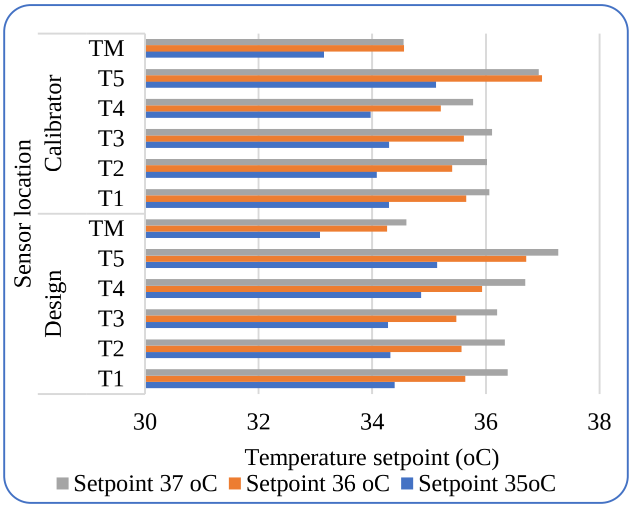

FIGURE 4. The comparison between the design and calibrator unit for three setpoints (35, 36, and 37 degrees Celcius) in the certain locations T1, T2, T3, T4, T5, and Tm.

TABLE 2

Temperature parameter measurement error between the design and calibrator unit for all temperature set point (35°C, 36°C, and 37 °C) on five certain location T1, T2, T3, T4, T5 and TM. The measurement was conducted 20 times for each setpoint including the noise error. Note: in this study, the claibrator used is Fluke Biomedical INCU II and the design is the proposed method.

Measuring Point	Error			
	35°C	36 °C	37 °C	With DC Fan
T1	-0.28674	0.03739	-0.88732	-
T2	-0.71652	-0.45420	-0.88389	-
T3	0.05831	0.36503	-0.24232	-
T4	-2.61724	-2.06400	-2.55753	-
T5	-0.05694	0.74125	-0.92964	-
TM	0.21367	0.85604	-0.15677	-
Noise (dB)	3.18085	5.25490	-1.72733	-2.70669

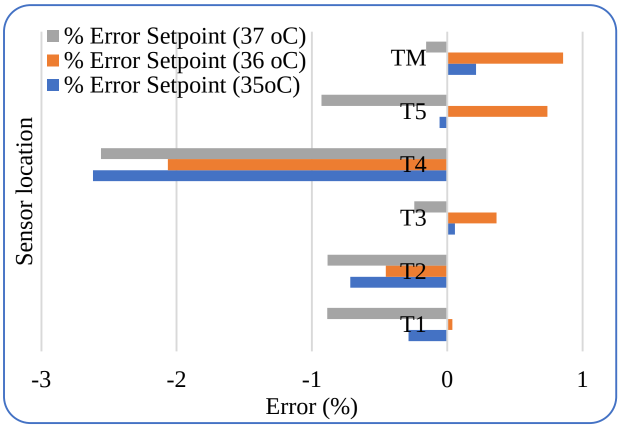

FIGURE 5. Temperature parameter measurement error between the design and calibrator unit for all temperature set point (35°C, 36°C, and 37 °C) on five certain location T1, T2, T3, T4, T5 and TM. The measurement was conducted 20 times for each setpoint. Note: in this study, the claibrator used is Fluke Biomedical INCU II and the design is the proposed method.

TABLE 3

Airflow measurement error between the design and calibrator unit for all temperature set point (35°C, 36°C, and 37 °C). The measurement was conducted 20 times for each setpoint. Note: in this study, the claibrator used is Fluke Biomedical INCU II and the design is the proposed method.

Setting (°C)	Measurement Tool	Average (m/s)	Error (%)
35	Design	0	<1.0
	Calibrator	<0.1	
36	Design	0	<1.0
	Calibrator	<0.1	
37	Design	0	<1.0
	Calibrator	<0.1	
35	Design	0.63167	-2.710
	Calibrator	0.615	

In TABLE 1, when the temperature setting is 35, 36, 37 degrees, the error value is <100% because the module cannot read airflow below 0.1 m/s.

TABLE 4

Humidity parameter measurement error between the design and calibrator unit for all temperature set point (35°C, 36°C, and 37 °C). The measurement was conducted 20 times for each setpoint. Note: in this study, the claibrator used is Fluke Biomedical INCU II and the design is the proposed method.

Setting (°C)	Measurement Devices	Average	Error (%)
35	Design	62.483	-0.106
	Calibrator	62.416	
36	Design	56.550	1.538
	Calibrator	57.433	
37	Design	57.933	1.278
	Calibrator	58.683	

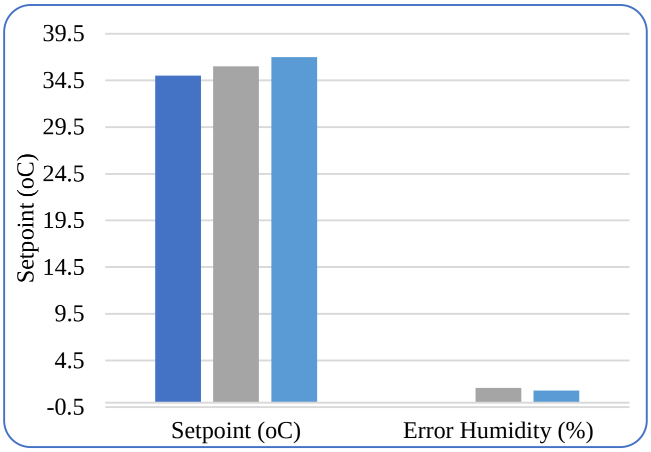

FIGURE 6. Effect of temperature setpoint value (35°C, 36°C, AND 37 °C) on infant incubator machine to the humidity parameter measurement error.

Meanwhile, when setting 35 degrees with treatment, the error value is -2.71002%. The reading of the module value is still not stable, so that error is still obtained. In TABLE 4, the humidity error value is below 2%. The reading of the module value is stable enough to obtain the error. Additionally, the effect of the difference setpoint on the temperature is shown in FIGURE 6. Additionally, every temperature setpoint has different error humidity. FIGURE 6 shows the final proposed design as an INCU analyzer with an Android phone connection.

(a) (b)

FIGURE 7. The proposed design (INCU ANALYSER) is based on Android application, (a) top view of the model, and (b) side view of the model.

IV. DISCUSSION

The results showed that the proposed design could be used to measure the parameters of the baby incubator. This module consists of an LM35 to measure the temperature, MPX5010DP sensor to detect the airflow rate in the baby incubator chamber, a mic condenser to sense the noise in the chamber and a DHT22 sensor used to detect humidity in the baby incubator chamber. All parameters are displayed on the liquid crystal display and Android mobile phone display. The values of the parameters are transmitted over the Bluetooth by using the HC-05 module. Arduino and Android mobile phone should be configured first so that all parameters can be sent and received correctly. All of parameters will be processed sequentially in a separated list by giving each variable's a symbol "|". The measured variables in real-time are displayed in the column according to the parameter name. Additionally, the user can press the start button to start saving data and data will be saved every 30 seconds. The data will be stored in the internal storage in a specific folder with the file name "IncuA.txt".

In this study, programming on android applications is made using MIT App Inventor (Version 2.62). It is an online and open-source application to build functional application for Android and IOS. Furthermore, for the acquisition of data for various parameters, the Arduino program used two timers to update the display and saving the data. The first-timer was run for every second to display parameter data, and the second-timer was to save data at regular for every 30 seconds.

The proposed design was then compared with a calibrator unit INCU II to validate the measured parameters of the proposed model. The smallest error resulting from the humidity parameter was -0.106% at 35°C, and the largest error was 1.538% at 36°C. Meanwhile, the airflow parameter gets an error of 2.710% when a fan is applied. On the other hand, the smallest temperature error value of 0.037% at T1 setting temperature of 36°C and the largest error of 2.617% at T4 setting temperature of 35°C. Meanwhile, for the noise parameter, the smallest error value is - 1.727% at 37°C setting, and the largest error is 5.254% at 36°C setting.

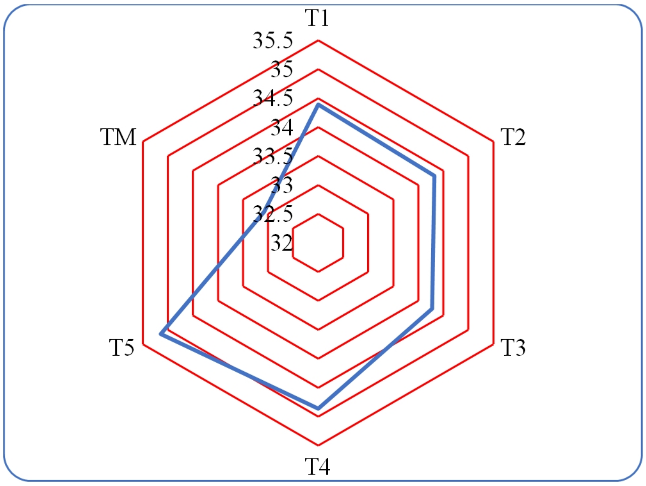

FIGURE 8. The radar graph shows the temperature distribution in the infant incubator room among T1, T2, T3, T4, T5, and TM for temperature setpoint 35 °C.

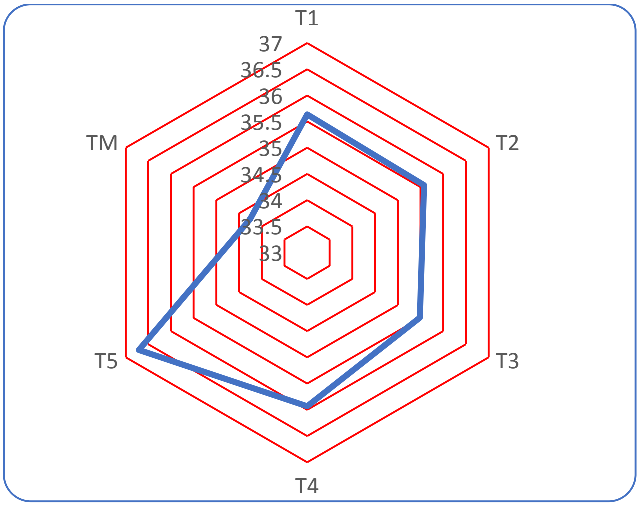

FIGURE 9. Radar graph shows the temperature distribution on the infant incubator room among T1, T2, T3, T4, T5, and TM for temperature setpoint 36 °C.

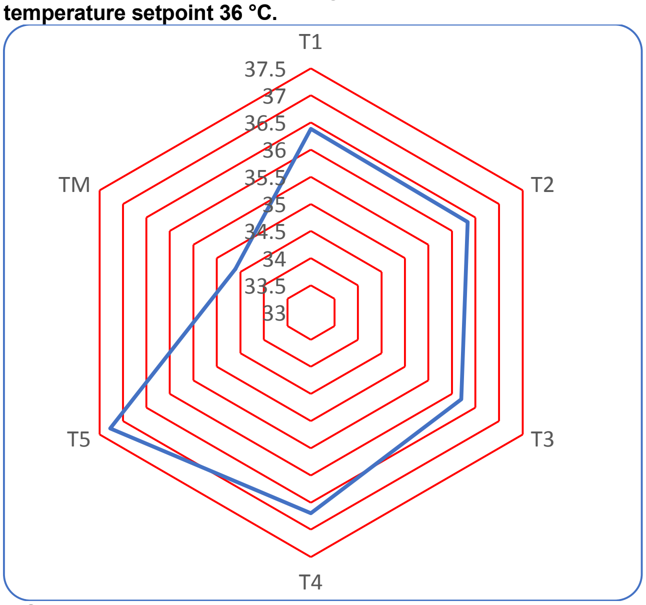

FIGURE 10. Radar graph shows the temperature distribution on the infant incubator room among T1, T2, T3, T4, T5, and TM for temperature on setpoint 37 °C.

FIGURES 8, 9, and 10 show an in-depth analysis of the temperature distribution on the infant incubator machine for temperatures of 35°C, 36°C, and 37°C, respectively. The radar graph shows that the incubator temperature that is close to the setpoint is at point T5, which is located at the midpoint of the incubator chamber. The temperature measurement point at T4 occupies a measurement point that is close to the setpoint temperature after the T5. In addition, the measurement points T1, T2, T3 produce temperature measurements that have a larger difference to the setpoint temperature. Furthermore, the TM temperature measurement point is far from the setpoint; this is understandable because the position of the measurement point is under the mattress.

The limitations of this study are that storage can only be applied through an application on Android. When users have not installed the application, they can not save it in storage memory. Processing measurement data is also manual by importing storage data into excel. There is no graph display to know when the state is stable. Based on TABLE 1, the airflow sensor still cannot detect airflow correctly. In contrast, the airflow sensor shows inconsistent measurement results in the given treatment so that a significant error is still obtained.

The development of an INCU analyzer based on an Android application can be implemented for general incubator machine measurements as well as for routine calibration processes [23]-[25]. Android-based applications can make it easier for users or technicians to monitor the measurement process. Further development can be implemented by implementing a modern control system on the infant incubator machine, which is accompanied by monitoring through the Android application [26]-[28].

V. CONCLUSION

This study aims to optimize an Android phone for monitoring INCU analyzer measurements. It may be concluded that the system can be utilized to detect temperature, humidity, flow, and noise in the infant incubator chamber after the validation and calibration stages. When the temperature is below 25ºC, a differential amplifier circuit can eliminate the LM35 sensor's initial voltage. The smallest error value for the temperature parameter is 0.0373 percent at T1 for a temperature setting of 36ºC, while the biggest error is 2.617 percent at T4 for a temperature setting of 35ºC. The smallest error value in the noise parameter is -1.727 percent at 37ºC settings, and the biggest error value is 5.254 percent at 36ºC settings. For future development, multiple wireless connections should be proposed; thus, any device can easily connect to the INCU analyzer system.

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