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Development of ECG and Temperature Sensors for Infant Incubator

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Abstract

Infant incubators help doctors monitor all the different aspects of the child's environment and used to create conditions that were similar to those that were in the ideal conditions inside the mother's womb, preserving the life of premature babies and reducing infant baby death. This work aimed is to develop an IoT infant incubator with ECG and temperature sensors. This development of infant incubator utilizes the microcontroller Arduino Durian Uno as the primary CPU along with DS18B20 temperature sensor and AD8232 ECG sensor. With the advancement of Internet of Things (IoT) technology, this interface can be viewed through the Blynk application in the user's tablet, allowing for continously monitoring. The device has been developed successfully, and both sensors are operational. Four healthy people were invited to participate in the ECG reading measurement and the recorded BPM is between 108 and 144. However, the ECG sensors has a low accuracy, with the percentage error around 32% to 55%. On the other hand, the temperature sensor has a low variance value between 0.02 and 0.49 indicating that the sensor is very accurate.

1. Introduction

The World Health Organization (WHO), which was founded by the United Nations (UN), is the body in responsibility of tackling both communicable and non-communicable disease on a global scale. Worldwide, more than one in ten pregnancies result in premature birth, according to WHO (estimated 15 billion babies per year). In contrast to a full-term pregnancy, which is considered to be 40 weeks long, the Oxford Dictionary defines preterm as "born or occurring after a pregnancy significantly shorter than normal, especially after no more than 37 weeks". according to gestational age, preterm births can be divided into three categories: intermediate to late preterm (32-37 weeks), very preterm (28-32 weeks), and extremely preterm (<28 weeks)[1].

In addition, premature births are among the factors that contribute to the high infant mortality rate. Infants that were born prematurely need special care, especially when it comes to ensuring that the temperature of their surrounding is stable which premature babies should be kept at a temperature between 35°C and 36°C while they are still within the womb[2]. Infant incubator helps doctors monitor all the different aspects of the child's environment and used to create conditions that were similar to those that were in the ideal conditions inside the mother's womb, preserving the life of premature babies and reducing infant baby death. Infant incubators are crucial pieces of equipment that can save the lives of many premature babies[3]. For many years, medical professionals have utilized neonatal and pediatric incubators also known as infant incubators to treat sick or preterm newborn infants. Doctor Stephane Tranier created the first incubator in a Paris maternity ward in the 1890s, and since then, there have been notable advancements in the development, manufacture, and use of infant incubators. The system of regulating environmental parameters like temperature, relative humidity, air flow rate and oxygen concentration necessary for the medical treatment of particular illness can be analyze as high-tech equipment at that moment[4].

Premature babies have issues since their organs are still developing and they lack body mass. As a result, babies may struggle to breathe, maintain a healthy body temperature, or get enough light. The materials and technology in an incubator must be enough to handle the range of issues that a premature newborn may encounter. Besides that, hospitals and other healthcare facilities are the only places where infant incubators are used. As a result, it will be difficult for families to access the hospital, especially those who live in outlying places. Additionally, current baby incubators are only fitted with a few settings and lack of user feedback mechanism. Therefore, an incubator should be able to measure the baby's movement, weight, temperature, humidity, and luminosity for this purpose.

Therefore, this work focuses on the development of IoT infant incubator with ECG and temperature sensors, measuring the ECG and temperature signals and analyzing the performance of the developed system. On the other hand, the scope of this research can be divided into three phases. Phase 1 covers the development of hardware, phase 2 involves the software development using programming of Arduino Genuino and final phase covers the functionality testing of the overall system.

2. Materials and Methods

Fig. 1 shows the overall block diagram of the overall system. Firstly, the electrical activity of the infant's heart will be detected by ECG sensor while the temperature sensor will detect the temperature inside the incubator. Then, all the data obtained from the sensors will be processed by microcontroller and send wirelessly to Blynk IoT which displayed through Samsung A7 Tablet. When the temperature is below or over the predetermined value, the buzzer will activate and give alert to the guardians or users.

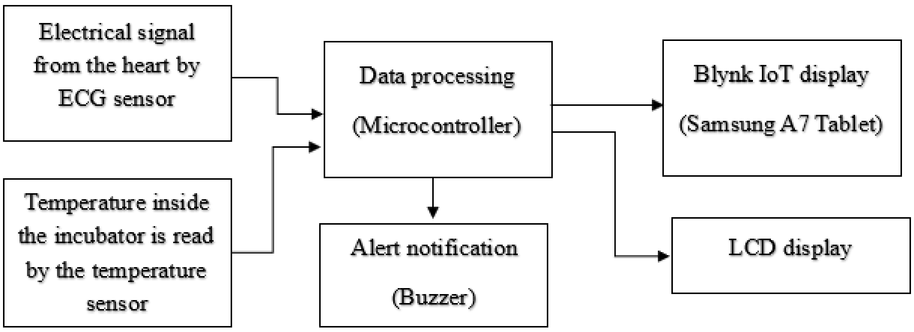

Fig. 1 *Block Diagram for Overall System*

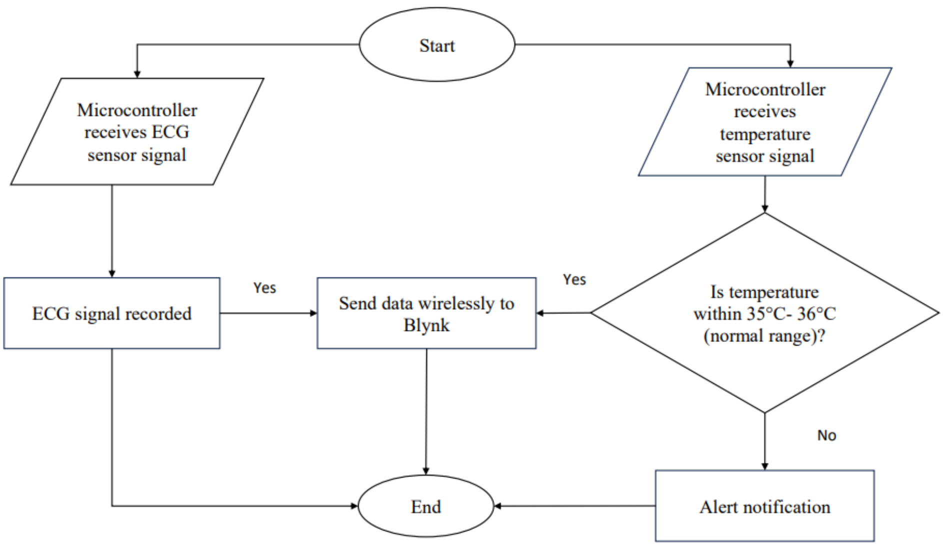

Fig. 2 *Flowchart of the system*

Fig. 2 shows the flowchart of the develop system for infant incubator. Firstly, the ECG sensor will detect the heart activity, meanwhile the temperature reading of normal range which is 35°C and 36°C inside the incubator will be detected by the temperature sensor. Then, the microcontroller will control all the operations of the system and send the data wirelessly to Blynk application. In addition, a notification from buzzer will alert the users if the temperature is deviated from the desired level.

2.1 Detection of PQRST of ECG Signal and Incubator Temperature

The PQRST peaks of ECG signal are detected using 3-lead electrode. The RA (red) electrode must be placed under the right clavicle, mid-clavicular line inside the ribcage frame, LA (yellow) electrode should be placed under the left clavicle, mid-clavicular line within the rib cage frame, and LL (green) electrode is placed on the lower left abdomen within the ribcage frame [5]. In addition, to acquire good quality tracing, adequate skin prep is required. First, select the selected chest electrode insertion areas, avoiding placing electrodes over bony prominences such as clavicles. To improve electrode skin contact, gently clean and abrade electrodes sites using a dry swab to remove loose skin cells, body oil, and sweat [6].

When the prototype is turned on, the DS18B20 temperature sensor will immediately detect the incubator temperature. As a result, the sensor is operational when the temperature value is displayed on the LCD display. In order to test the sensor's accuracy, take the temperature within three different conditions.

2.2 Error Analysis and Accuracy of ECG and Temperature Sensors

Functionality performance and accuracy of the ECG and temperature sensors are important for this development. Equations (1) is used to calculate the percentage error between the developed device and measured reading from pulse oximeter while equations (2), (3) and (4) are used to calculate mean, variance, and standard deviation to verify the temperature readings.

$$Percentage\ Error\ (\%) = \left|\frac{Develop\ device - Pulse\ oximeter\ reading}{Pulse\ oximeter\ reading} \times 100\right| \quad (1)$$

$$Mean = \frac{\sum readings}{Number\ of\ reading} \quad (2)$$

$$Variance = \frac{\sum(Reading - mean)^2}{Number\ of\ reading} \quad (3)$$

$$Standard\ Deviation = \sqrt{\frac{\sum(reading - mean)^2}{Number\ of\ reading}} \quad (4)$$

3. Result and Discussion

This section discussed the results obtained from this research work.

3.1 Prototype of Develop System

Fig 3 shows the hardware set-up of the prototype device. The casing of the prototype was made up from plastic, usually used for electronic box. The DS18B20 temperature sensor and AD8232 ECG sensor both are connected to the pins of Arduino Durian Uno. Then, an ESP8266 Wi-Fi module is connected to the ESP8266 port for IoT connection. A push button is placed on the top of the prototype, functioning to turn on and off the device. As for the output display, an I2C LCD display is used to display temperature value by connecting the module with SKU cable to I2C port on the microcontroller board meanwhile a buzzer is used as a notification to notify the user.

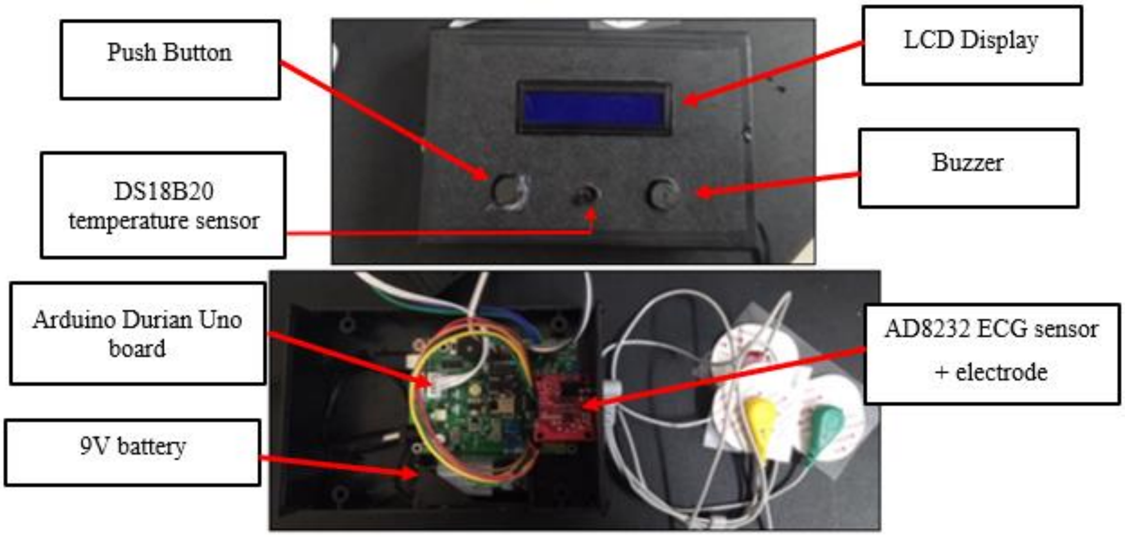

Fig. 3 *Prototype of ECG and Temperature for Infant Incubator*

Fig 4 (a) shows the temperature reading on the LCD display from prototype device when the device is on. Meanwhile, Fig 4 (b) shows the IoT platform as a user interface by using Blynk IoT application displayed on a Samsung A7 Tablet.

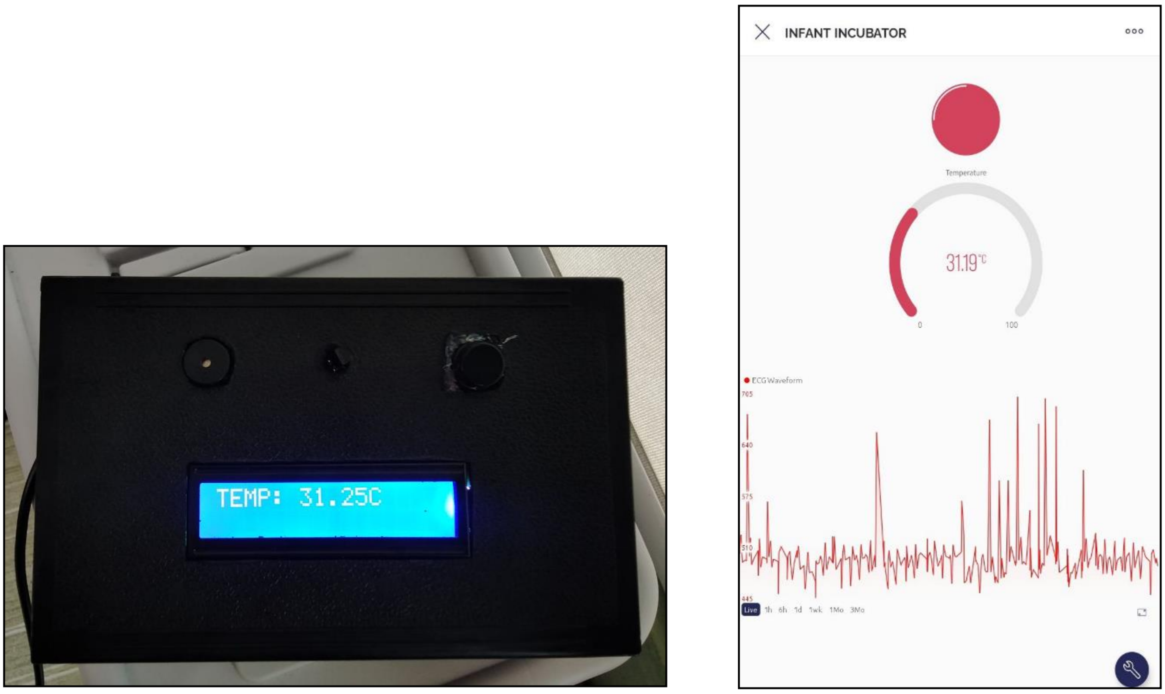

Fig. 4: *a) Temperature value on LCD and b) User Interface for IoT Platform using Blynk Application on Tablet*

3.2 Performance Evaluation

This subchapter explains the performance analysis of PQRST peak detection and incubator temperature. For testing the prototype on human subjects, four subjects were recruited. Their informed consents were obtained, and the experiment was conducted following the ethical guidelines from Helsinki Declaration. Table 1 presents the subject's profile.

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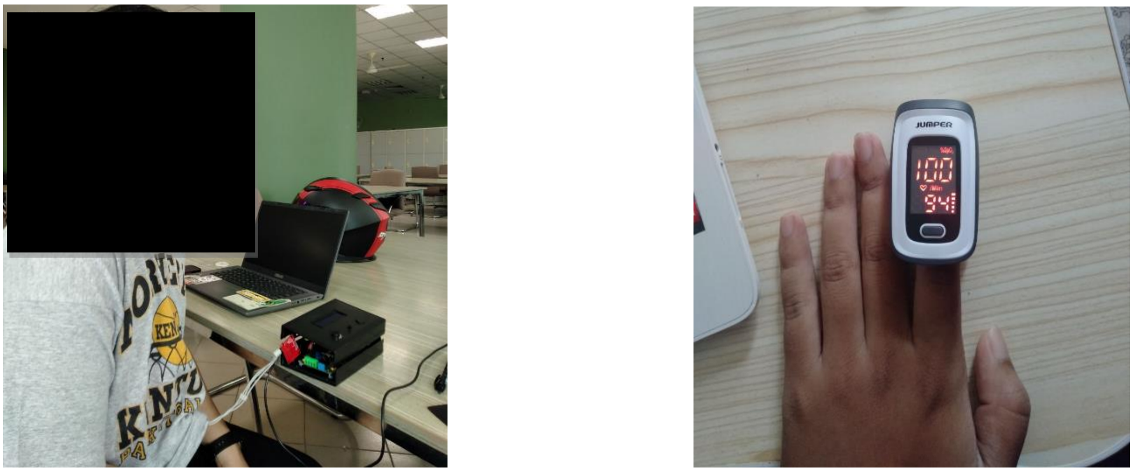
Table 1 *Subject's Profile*

Subject	Gender	Age	Weight (kg) & Height (cm)	Smoker/Non-smoker
A	Male	27	75 kg & 172 cm	Smoker
B	Male	24	83 kg & 172 cm	Non-smoker
C	Female	24	95 kg & 172 cm	Non-smoker
D	Female	24	55 kg & 153 cm	Non-smoker

3.3 Detection of PQRST of ECG Signal and Incubator Temperature

Several tests were carried out in order to get the ECG waveforms based on the presence of PQRST peaks as well as temperature readings from the incubator. Firstly, the electrode is positioned as determined by the medical practitioner. Because position is the most important factor in identifying ECG recordings, the ECG waveform is recorded when the individual is at rest, relaxed, and in proper body condition, which could lead to fluctuations in the heart rate, mean QRS axis, amplitude, duration, and morphology, as well as changed in the mean corrected QT interval [7]. Then, this ECG reading is recorded within 50 seconds. Fig 5 (a) is the example of a subject undergoing the ECG detection test whereas Fig 5 (b) shows the heart rate testing using a pulse oximeter.



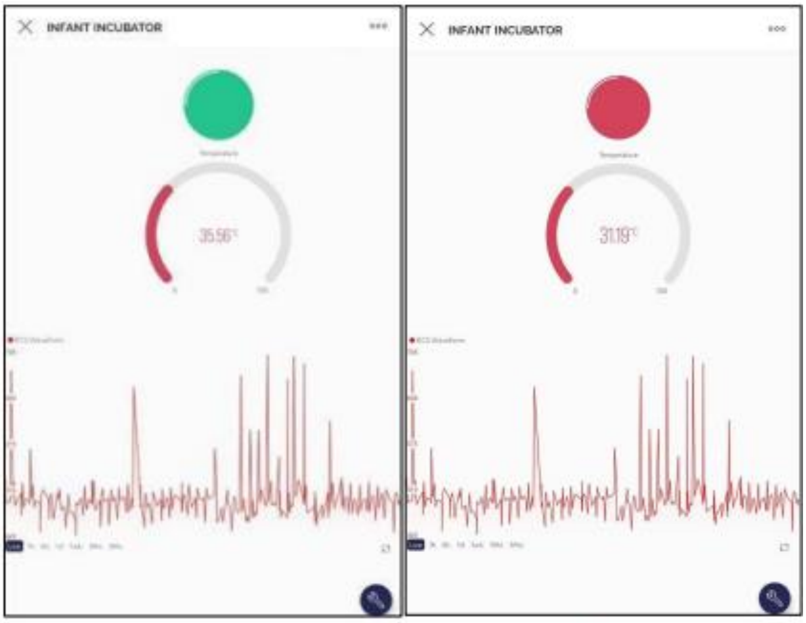
(a) (b)

Fig. 5: *a) Example of Subject A undergoing the experiment and b) Example of Heart Rate Testing using Pulse Oximeter*

Fig. 6 *Exampe of temperature taken at outdoor area*

In addition, the detection of temperature is conducted by placing the DS18B20 sensor in three different temperature conditions, includign ambient temperature area, air-conditioned room set at 22 degrees, and the outside area temperature at the peak hour, which taken at 1 o'clock. Fig 6 shows the evidence of experiment conducted at the outside area. All those conditions were measured for three times at one-minute intervals.

Fig. 7 (a) shows the Blynk interface when the temperature is between 35 and 36 degree Celsius. The led turn to green and buzzer will stop blaring at this point. Meanwhile, Fig. 7 (b) shows the led in the Blynk application turns to red when the temperature recorded by the DS18B20 is below or above the temperature range and the buzzer will be activated.



(a) (b)

Fig. 7 *Blynk Interface when (a) temperature in normal condition and (b) temperature not within the specified range*

3.4 Analysis and Detection of ECG Signal Acquisition

Fig. 8 represents the outcome of an ECG signal recorded from a healthy 27-year-old male who is a smoker. According to the image, the ECG signal is normal, with PQRST peak plainly visible. The estimated beat per minute (BPM) is 144 when the detected R peak is 12.

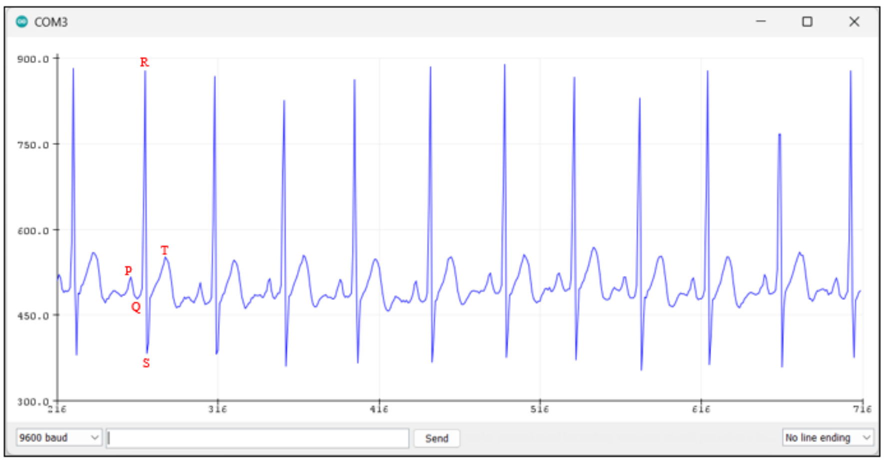


Fig. 8 *ECG Waveform obtained from Subject A*

Fig. 9 shows the result for ECG waveform collected from Subject B, a 24-year-old guy who does not smoke. The ECG signal appears organized to the human eye, with a crisp PQRST peak, free of noise and distortion. Furthermore, the baseline is consistent and free of drift. The estimated heart rate is 108 bpm with 9 R peaks detected.

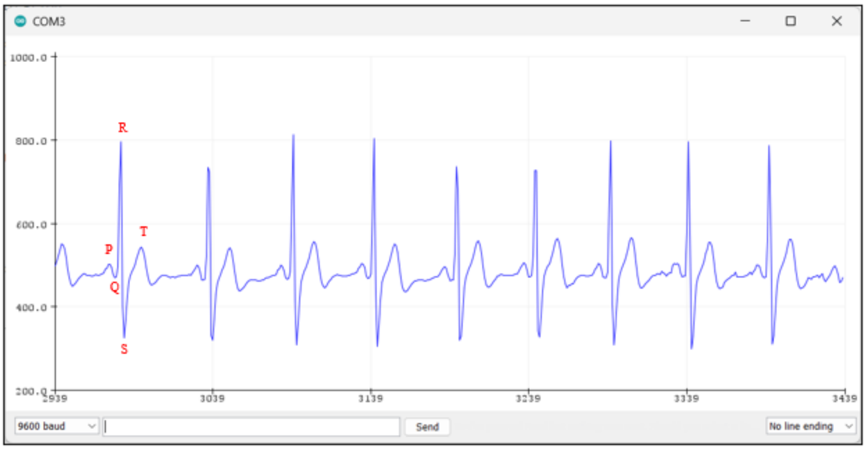


Fig. 9 *ECG Waveform obtained from Subject B*

Fig. 10 shows the result for ECG waveform collected from Subject C who is 24 year old woman. The PQRST peak can be seen, however the signal is masked by artifacts and distortions, resulted from the subject who did not sitting properly. The estimated heart rate reading is 132 bpm since there are 11 R peaks were detected during the testing period.

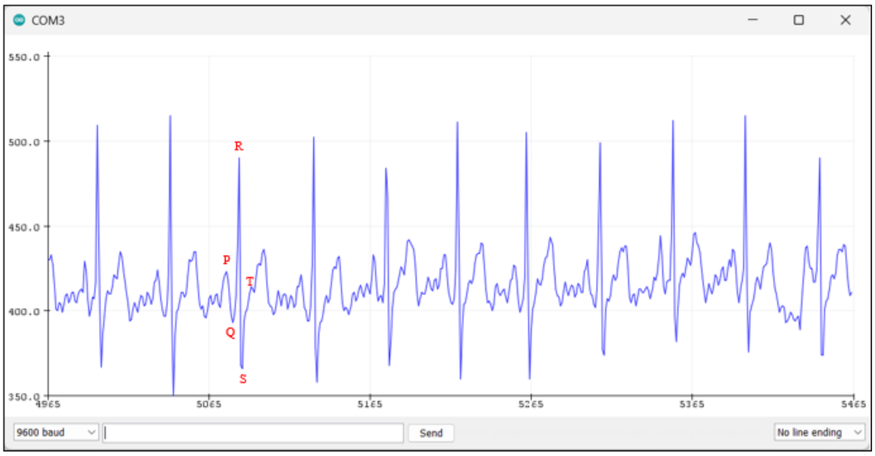


Fig. 10 *ECG Waveform obtained from Subject C*

Fig. 11 depicts the ECG waveform obtained from a healthy 24-year-old woman. The PQRST peak is also visible with a signal that has less interference from minor movements. Aside from that, the ensuring baseline shift did not particularly noticeable. The calculated heart rate is 144 bpm with 12 R peaks detected.

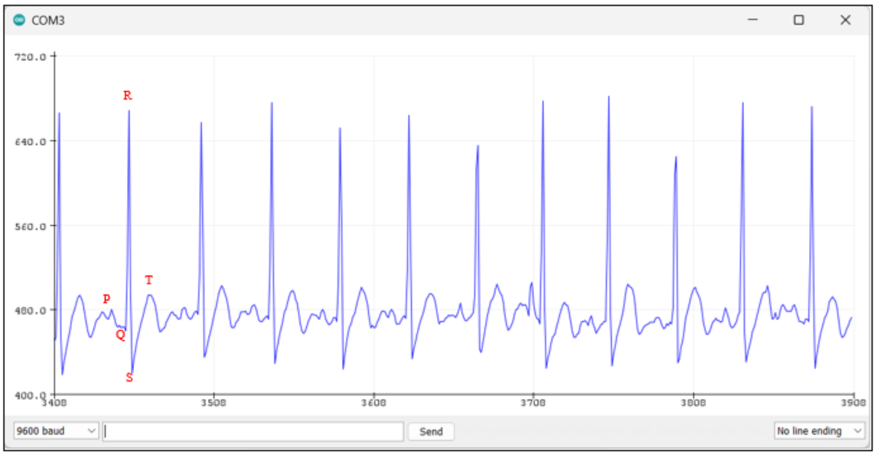


Fig. 11 *ECG Waveform obtained from Subject D*

Table 2 shows the result for heart rate reading obtained from developed device and fingertip pulse oximeter brand Jumper. The percentage error analysis is used to evaluate the accuracy and precision of the ECG signal measurement. According to the table, the heart rate readings from the develop device and the pulse oximeter are significantly different. Besides, the minimum percentage error is 32% and maximum percentage is 54.84%, due to the disparity in the reading value derived through calculation from the ECG signal and also the reading from the pulse oximeter. The presence of a big error reading demonstrates that the heart rate reading acquired from the ECG signal is highly incorrect.

Table 2 *Comparison Result for Heart Rate*

Subjects	Heart rate (BPM)		Error Analysis (%)
	Develop device	Pulse oximeter	
A	144	100	44
B	108	80	35
C	132	100	32
D	144	93	54.84

3.5 Analysis and Discussion of Incubator Temperature

Several related analysis, such as computation of mean, variance, and standard deviation, can be used to determine the sensor's accuracy. These computations will provide information about the average, spread and consistency of temperature readings from DS18B20 sensor in various temperature conditions. Table 3 shows the result for temperature taken 3 times in different temperature conditions with statistical analysis. The readings detected by the DS18B20 sensor can be used to determine its accuracy.

The sensor provides a mean value of 30.9°C in room temperature circumstances, with a low variance (0.03) and a standard deviation of 0.17, indicating consistent and accurate data. In an air-conditioned room, the sensor has a mean of 24.56°C, a low variance (0.02), and a standard deviation of 0.14, also showing accurate and consistent performance. Outdoors, however, the sensor's mean value rises to 38.1°C, with a greater variance (0.49) and a standard deviation of 0.7, indicating increased unpredictability. The observed changes in variability and mean values across contexts imply that external variables may influence the sensor's accuracy and performance, particularly in demanding outdoor situations.

In addition, in controlled situations such as room temperature and air-conditioning room, the sensor appears to work within the indicated accuracy range, despite the manufacturer's fixed inaccuracy of ±0.5°C. However, performance in outdoor circumstances may be affected by other factors, resulting in readings that depart from the declared fixed error.

Table 3 *Temperature taken for 3 times in different temperature conditions with statistical analysis*

	Reading 1	Reading 2	Reading 3	Mean	variance	Standard Deviation
Room temperature	30.7°C	30.9°C	31.1°C	30.9°C	0.03	0.17
Air-conditioned room	24.44°C	24.50°C	24.75°C	24.56°C	0.02	0.14
Outdoor area	37.3°C	38°C	39°C	38.1°C	0.49	0.7

4. Conclusion

In conclusion, an IoT infant incubator incorporating ECG and temperature sensors was successfully developed. Based on the data, the heart rate reading has a percentage inaccuracy ranging from 32% to 55%, however the temperature reading is quite reliable with low variance finding with around 0.02 to 0.49. In conclusion, this study was successful in meeting all the three of its aims, which were to design an IoT infant incubator with ECG and temperature sensors, as well as to measure the ECG and temperature signals, to let the users monitor the infant. The tablet monitoring collects temperature sensors data via the Wi-Fi, which is then shown on a user-friendly application such as Blynk IoT application. Families that reside in distant areas and find it difficult to get to the hospital can now use this device.

There are some suggestions for future development to improve the accuracy of the system. Some suggestions can be made to improve the work such as testing and collecting data in real situations, for example using a commercial infant incubator. Besides, continuing the research and techniques to achieve more precise heart rate readings using an ECG sensor.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author attests to having sole responsibility for the following: planning and designing the study, data collection, analysis and interpretation of the outcomes, and paper writing.

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