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Portable neonatus incubator based on global positioning system

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ABSTRACT

The role of baby incubator is crucial in assisting premature babies to adjust to their new surroundings. However, the current baby incubator causes challenges when used for emergency first aid. The challenge is often because of its cumbersome size, which makes transportation to referral hospitals difficult. To address this issue, portable neonate incubator based on the global positioning system (GPS) was developed. The results of implementation testing showed that the incubator system effectively monitored longitude and latitude coordinates, as well as the temperature and humidity of the incubator room, and the body temperature of neonates. Weighing approximately 5.8 kg, this incubator was versatile, compatible with both AC and DC voltage power sources, and came equipped with a carrying bag for easy transportation by midwives or medical personnel. Consequently, this development marked an innovative advancement in neonate incubator medical equipment, facilitating the swift tracking of the neonate incubator's coordinate position in case of unexpected events on the way to the hospital.

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1. INTRODUCTION

According to the World Health Organization (WHO), approximately 15 million births worldwide each year are premature, with over one million resulting in immediate mortality [1]. Indonesia is ranked fifth globally in the prevalence of premature births. Generally, premature babies face various complications due to an underdeveloped immune system, impacting their entire growth and development [2]. Neonates, also known as premature or critical newborns, are babies born with a gestational age of less than 37 weeks and often have a low birth weight, defined as less than 2,500 grams. The immature state of baby's organs prevents proper functioning, particularly in those born between 24-27 weeks, who face low survival odds without intensive care [3], [4]. The baby incubator is a crucial medical device designed to maintain a constant temperature in the incubator room. Furthermore, it serves as a crucial tool for the treatment of critical neonates, providing controlled warmth and humidity [5]–[8]. However, standard baby incubators prove less efficient in emergencies due to their cumbersome size, necessitating the development of easily transportable incubators.

Transport incubators, specifically designed for neonatal care, enable the safe transfer of critical or premature babies between hospitals with adequate neonatal intensive care units [9]. Studies have shown no significant difference between the use of Kangaroo mother care (KMC) transport and traditional transport incubators, which is the current standard of care [10]. To address the risk of losing transportation incubators during transfers, the implementation of a tracking system becomes important.

The study aimed to design portable neonate incubator equipped with a global positioning system (GPS) sensor. Furthermore, the sensor will continuously track the coordinates of the incubator throughout its journey to the hospital. This innovative approach enables medical personnel to monitor the incubator's position in real-time via smartphone, thereby preventing potential loss or fatalities during the referral process.

2. LITERATURE REVIEW

This study is a continuation of prior exploration comprising the development of a foldable portable neonate incubator with the capacity for temperature and humidity detection, maintaining a range of 34 °C to 37 °C and 60% to 80% humidity [11]. A corresponding alert system for premature baby incubators via short message service (SMS) has also been devised [12]. This system facilitates the transmission of temperature and humidity information from the incubator to a smartphone through global system for mobile communication (GSM). An additional aspect of this study relates to the wireless premature baby monitoring system [13]. This system describes incubator temperature and humidity on a personal computer, providing information on the baby's heartbeat status. Moreover, an internet-based application monitors the temperature and humidity of the baby incubator [14]. Several studies on neonate incubators have investigated monitoring systems. For example, a Wi-Fi-based system has been designed to monitor incubator temperature, humidity, and the baby's skin temperature, while data is transmitted to a host computer in the nurse's room [15]. Simultaneously, GSM technology is used in incubator systems for continuous monitoring and data transmission via Bluetooth, although these systems are constrained to line-of-sight communication and are unsuitable for long-distance use [16].

To enhance neonatal care, the study introduces a closed-loop control system, regulating temperature, relative humidity, and light intensity in a neonatal incubator. This system, equipped with light-emitting diodes (LEDs) to prevent jaundice, integrates an alarm system and GSM technology for parental alerts [17]. In the measurement of body temperature and heart rate, the incubator system uses LM35 precision centigrade temperature sensors and pulse sensors connected to an Arduino Uno controller board. It should be acknowledged that wireless data transmission is facilitated through the Arduino Wi-Fi module [18]. Furthermore, a cost-effective embedded device for real-time tracking of newborns in incubators has been designed, featuring an liquid crystal display (LCD) display and message alerts to phones [19]. Another system, monitoring temperature and humidity via a WI-FI network, uses a DHT22 temperature sensor and the values obtained were shown on a Nextion thin-film-transistor (TFT) screen [20]. Incorporating microcontroller systems, temperature sensors, weight sensors, heart rate sensors, and GSM modules, the study proposes a comprehensive monitoring system for portable incubators, enabling the detection and notification of the condition of premature babies [21]. This system incorporates features such as detecting baby's temperature, heart rate, weight, and voice in the incubator [22]. Regarding transportation incubators, an automatic temperature control system is established at a constant 37 °C under all conditions, minimizing the risk of neonatal hypothermia [23].

3. METHOD

This section describes the design of a GPS-based portable neonatal incubator system. The system architecture explains the supporting components of the incubator system including sensor systems, cloud database systems, and Android application systems. Hardware design describes the design of the incubator and lays out the components of the incubator system. The software design explains the creation of an application for incubator monitoring and the data flow system design explains the data processing process in the incubator monitoring application.

3.1. Systems architecture

The portable neonate incubator comprised the incubator, a sensor system, a cloud database system, and an Android application system. The sensor system integrated temperature sensors, incubator room humidity sensors, neonate body temperature sensors, and GPS sensors. The cloud database system stored values such as temperature, humidity, neonate body temperature, and position coordinates. The Android application retrieved these values from ThingSpeak and showed the output on a smartphone [15], as seen in Figure 1.

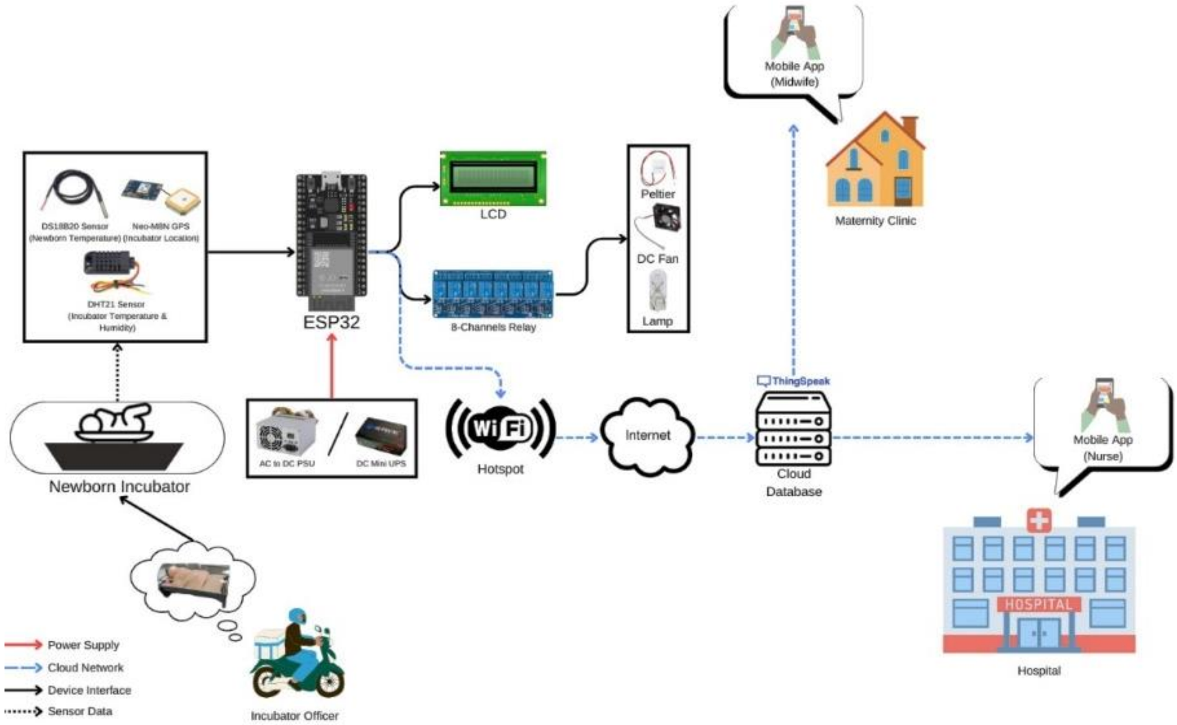


Figure 1. The system architecture of GPS-based portable neonate incubator

3.2. Hardware design

The portable neonate incubator was designed to measure 50×25×25 cm^3, which was made of acrylic material and divided into two parts. The lower part was used for electronic components and the upper part was used for neonates. Holes were made on the right and left side of the for the air circulation, as shown in Figure 2.

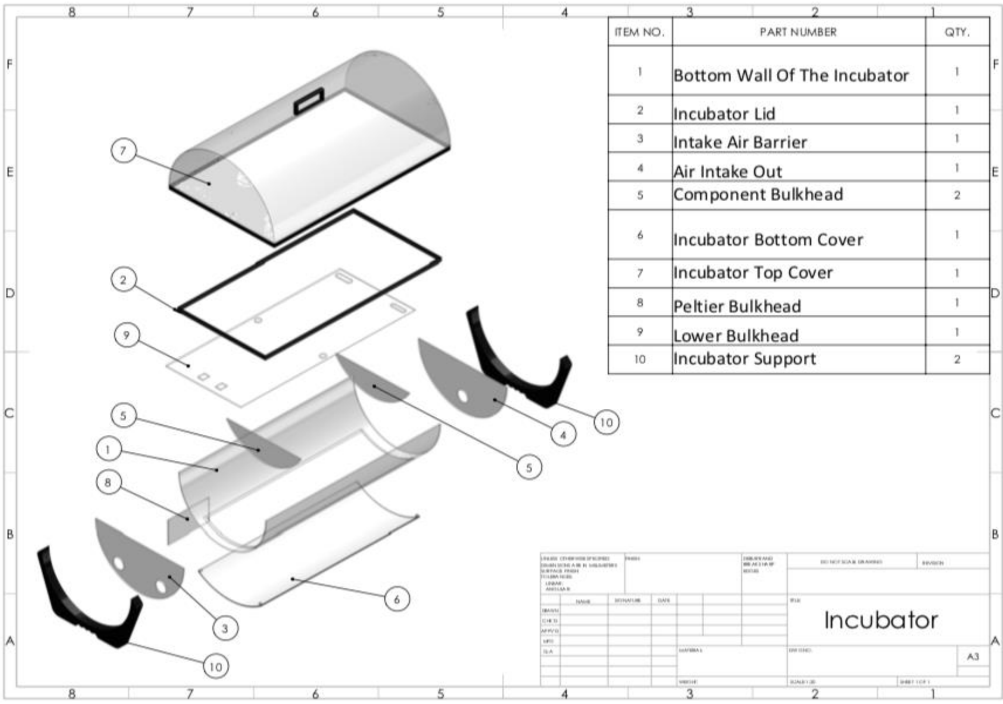


Figure 2. Design of portable neonate incubator

To ensure uniform circulation of air temperature and humidity inside the incubator, SolidWork software [24] was used to simulate the air flow process. The aim of this simulation is to obtain the position of the air holes and the position of the fan and Peltier so as to produce optimal air circulation in the incubator. Air circulation is needed to maintain the air conditions in the incubator so that the health of the neonate is maintained, as shown in Figure 3.

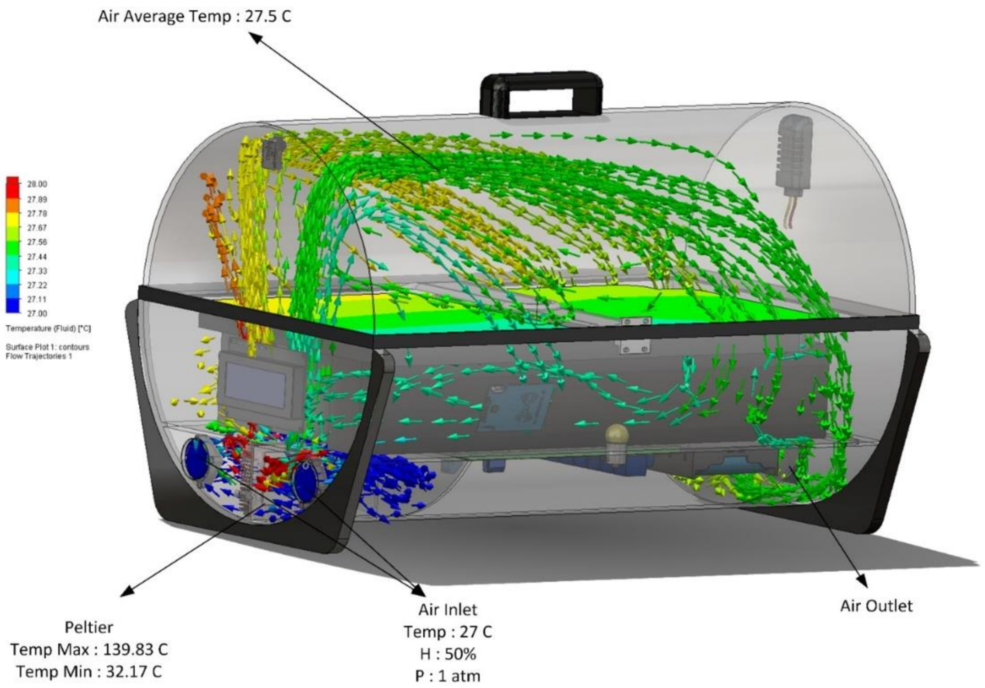


Figure 3. Simulation results of SolidWorks software

The sensor system used a DHT21 sensor to measure temperature and humidity in the portable neonate incubator room [25], with a measurement range of 34 °C to 37 °C for temperature and 60% to 80% for relative humidity. For neonate body temperature measurement, a DS18B22 temperature sensor was used [26], [27]. Fans circulated hot/cold air from the Peltier into the incubator room through a ducting system with inlet and outlet fans [28]. The NEO-M8M GPS sensor calculated the geographical location received from GPS satellites [29]. A Peltier cooling system [30] regulated the incubator chamber's temperature. The heating system used heat generated by a 25-watt, 12-DC lamp for easy spare part availability. An LCD module 2004 [31] showed coordinate values, incubator room temperature and humidity, and neonate body temperature. Component placement was shown in Figure 4.

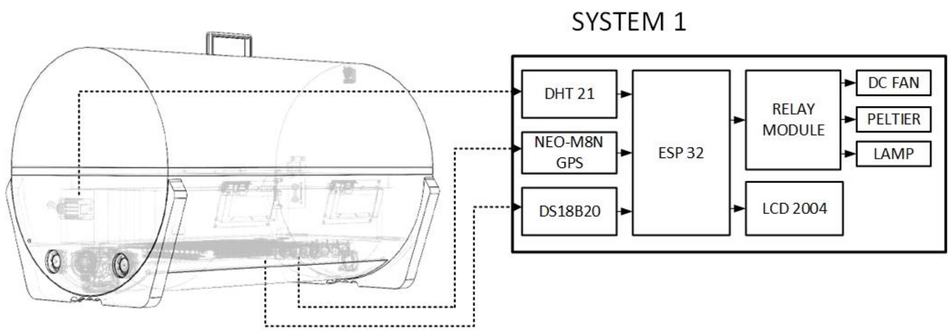


Figure 4. Positions and component blocks of the portable neonatal incubator

3.3. Software design

The GPS-based portable neonatal incubator monitoring application, developed with MIT App Inventor, an open-source platform using a block-based programming language [32]. The application structure consists of a condition monitoring, location monitoring and exit. The condition monitoring there are displays: Celsius indicator, Fahrenheit indicator, humidity indicator, incubator heat index indicator and body temperature. The location monitor there are options: map display, latitude, longitude and distance display, map display control, current position tracker and incubator position tracker, as shown in Figure 5

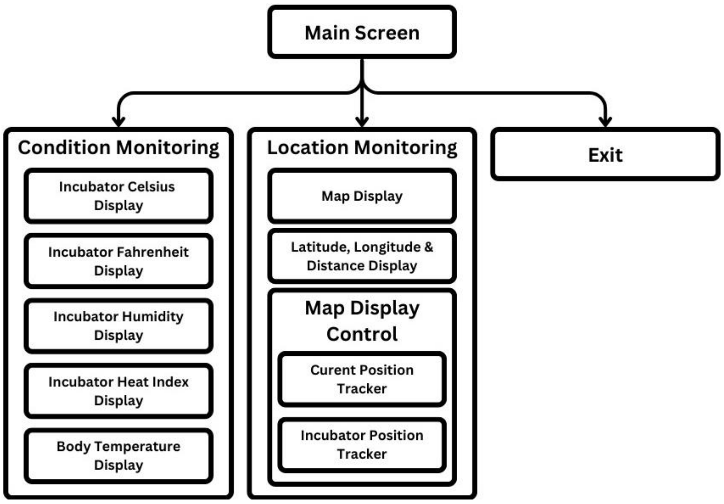


Figure 5. Structure diagram of portable neonate incubator monitoring application

When the application ran, the screen was divided into two sections, one for monitoring the position coordinates of the neonate incubator and another for monitoring the temperature, and humidity of the neonate incubator room, and the body temperature of the neonate. In the position coordinate monitoring section, a map showed the latest position of the portable neonate incubator, including latitude, longitude, and distance. The control section featured two text boxes for tracking the current position and tracking the incubator's position. The temperature monitoring section included a frame indicating the temperature, humidity, and neonate body temperature. Figure 6 showed the designed view of the portable neonate incubator system condition monitoring application.

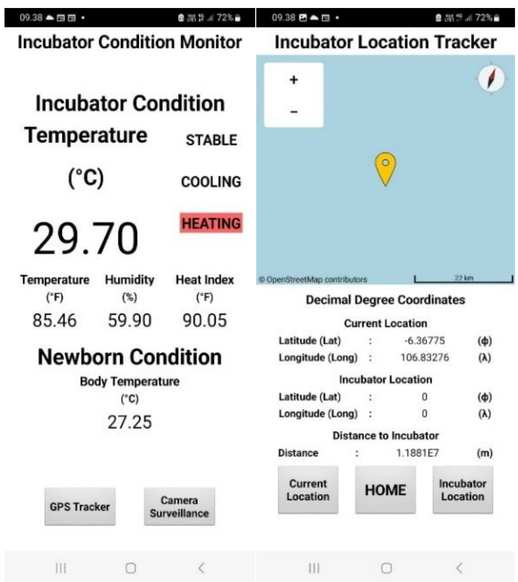


Figure 6. Design view of portable neonate incubator monitoring application

3.4. System data flow design

This monitoring application used the ThingSpeak IoT platform as a cloud database service to store sensor data from the system, accessible through the Android application. ThingSpeak was a web service designed for collecting, storing, and showing data, particularly focusing on input from sensor devices [33], [34]. Using App Inventor and ThingSpeak cloud service, the data flow diagram of the monitoring application was designed, as shown in Figure 7.

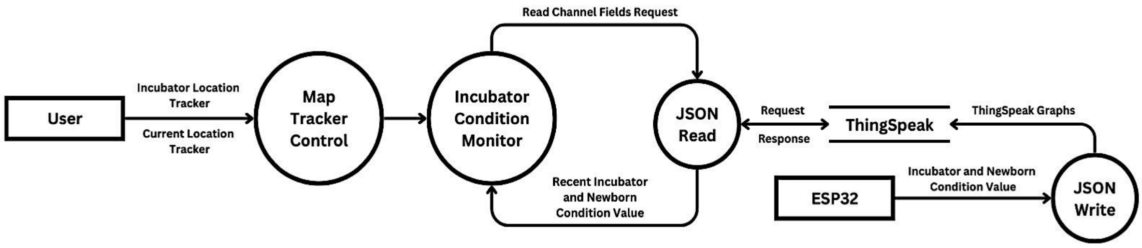
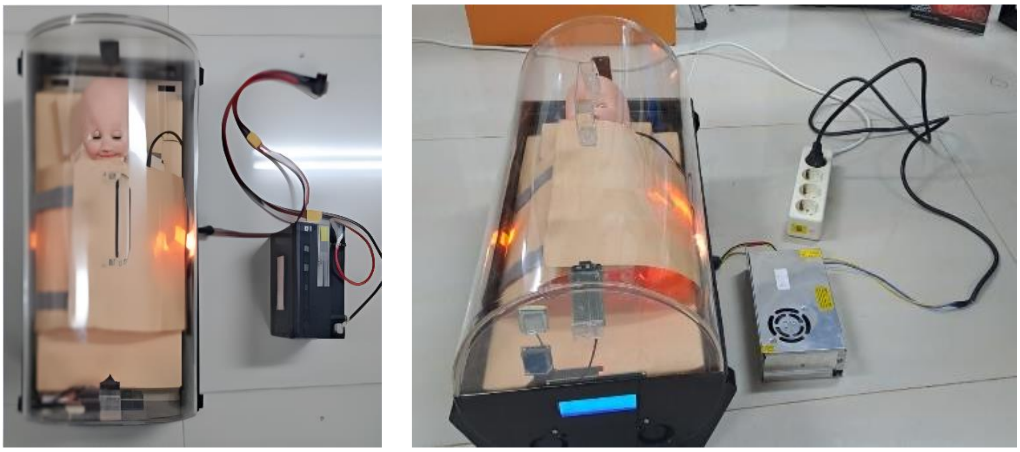


Figure 7. Data flow diagram of the monitoring application

From the ESP32 entity, incubator room condition values from the DHT21 humidity-temperature sensor, neonate body temperature condition from the DS18B20 sensor, and incubator position coordinates from the Neo-M8N GPS sensor were uploaded to ThingSpeak in JavaScript Object Notation (JSON) format using the Write API Key of the destination channel. This was done with the HTTP Post method over the internet network and stored in the graphical interface. From the user entity, the coordinates of the incubator location could be tracked based on the response of the latitude and longitude values requested by the application in JSON format using the Read API Key from the intended ThingSpeak channel. Subsequently, a button press on the application allowed users to view the incubator's location. For the user's location, latitude and longitude coordinate values were based on the location sensor on the smartphone, and a button press allowed users to see their location. The user could monitor the incubator room condition and the neonate's body temperature in the monitoring application, as shown in Figure 7.

4. RESULTS AND DISCUSSION

The design results of the GPS-based portable neonate incubator were shown in Figure 8. This GPS-based portable neonate incubator could operate using DC or AC power sources (Figures 8(a) and (b)). The AC source is used when the incubator is in the treatment room. The DC source is used when being taken to a referral hospital or as a backup during emergencies without available AC source.



(a) (b)

Figure 8. Prototype of GPS-based portable neonate incubator with (a) DC power source and (b) AC power source

4.1. GPS-based portable neonate incubator testing

Tests were conducted to observe the functionality of the NEO-M8M GPS sensor, DHT21 sensor, DS18B20 sensor, and monitoring application. Testing was carried out at two locations, including the initial position (Campus D) to the neonate incubator and from the neonate incubator to the destination position (Campus F6) within a 4.9 km distance, using the maps.google.com website service [35]. Testing incorporated setting five points for the neonate incubator to pass, and then five consecutive coordinates sent by the neonate incubator were recorded, as shown in Figure 9.

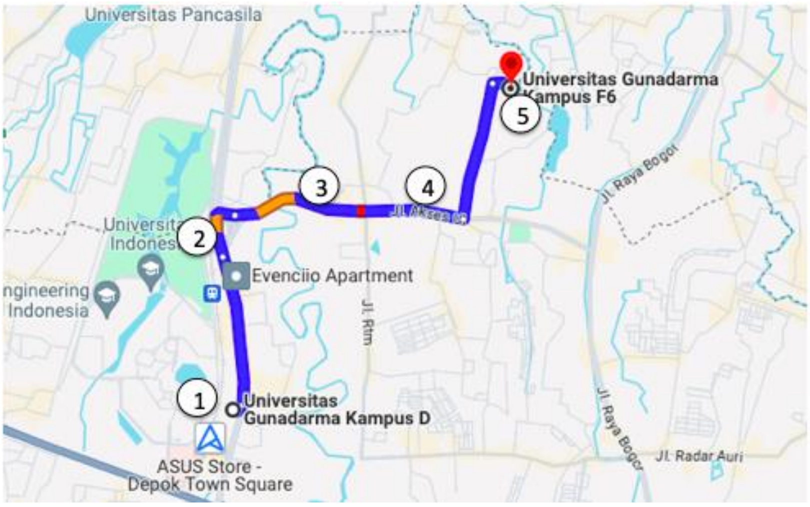


Figure 9. Testing five points that the GPS-based portable neonate incubator will pass through

Additional tests were conducted to determine the response parameters, including coordinate values of the neonate incubator's position, temperature and humidity of the neonate incubator room, and neonate temperature. These values were then uploaded to ThingSpeak while being shown in the monitoring application. In Figure 10, the GPS-based portable neonate incubator, to be transported by motorcycle from campus D to campus F6, was placed into a specially made bag.

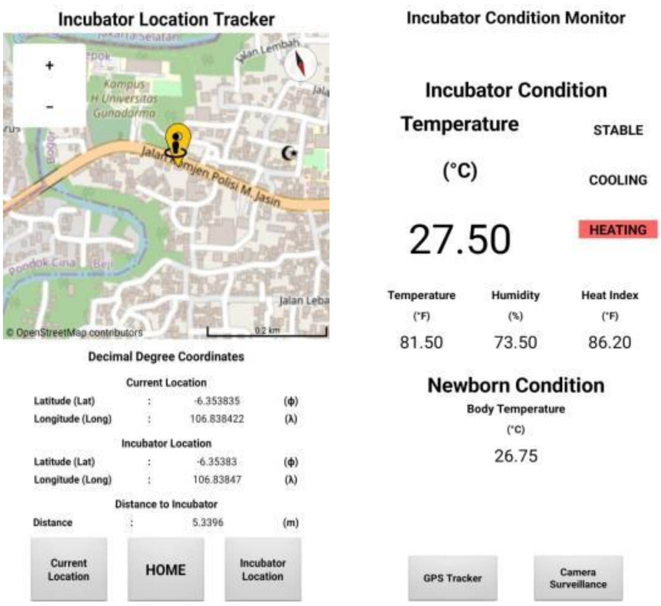
Figure 10. Testing the GPS based portable neonate incubator from campus location D to campus location F6

4.1.1. Monitoring application testing

Testing incorporated the connection between the portable neonate incubator and the application program, which indicated the travel point value of the portable neonate incubator, the temperature value, room humidity, and the neonate temperature value. Subsequently, the ESP32 was initialized, and then the NEO-M8N GPS sensor searched for a satellite signal to connect and obtain a position coordinate fix. When the satellite signal connection was unsuccessful due to disruptions in the NEO-M8N GPS sensor antenna line or the baud rate value being out of sync, the system followed a specific protocol. After the position coordinates were set, the GPS sensor retrieved the latitude and longitude values, marked by the LED indicator lighting up, as shown in Figure 11, before forwarding the outcome to the position coordinate sending function.

Figure 11. Testing GPS sensors receiving satellite signals

The monitoring application read the last value of the coordinates of the incubator position, the temperature and humidity value of the incubator room, and the neonate's body temperature value stored in the ThingSpeak cloud database. This occurred if the Neo-M8N GPS sensor had not connected to the satellite, and it read the latest value when the connection had been established. Display test of monitoring application are illustrated in Figure 12. In Figure 12(a), the view of the monitoring application after reading the coordinate value of the incubator position, the temperature and humidity value of the incubator room, and the body temperature value of the neonate was presented. In Figure 12(b), the conditions of the neonate incubator room included green signaled stability, indicating that the room temperature was between 34 °C-37 °C, blue denoting cooling for temperatures above 37 °C, and red signifying heating for temperatures below 34 °C.

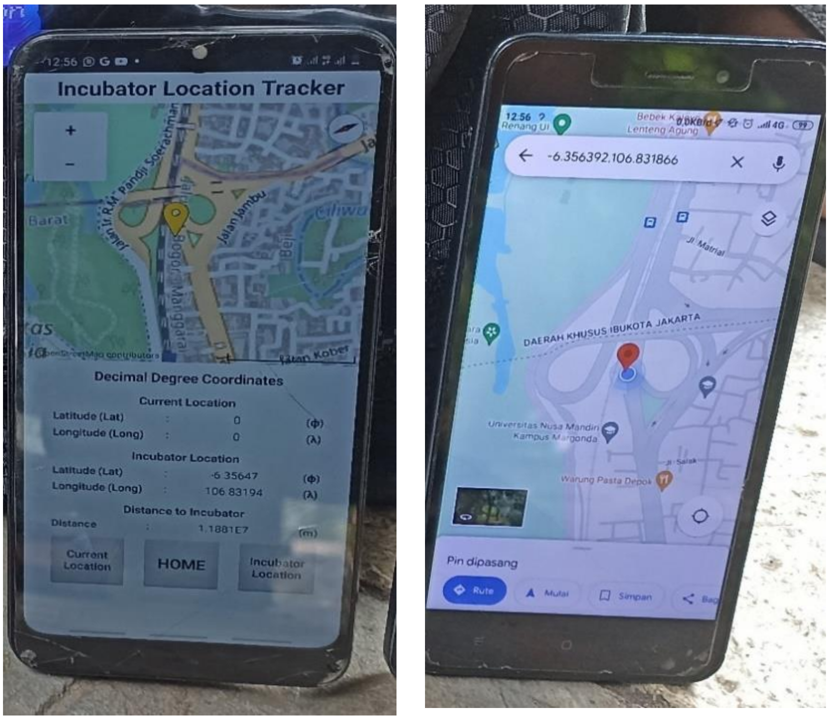


(a) (b)

Figure 12. Display test of monitoring application (a) coordinate value of incubator position and (b) temperature and humidity value of incubator room, body temperature value of neonate

4.1.2. GPS NEO-M8M sensor accuracy testing

GPS sensor testing was conducted by comparing the reference smartphone GPS sensor value with the NEO-M8N GPS sensor value, as shown in Figure 13. In Figure 13(a) is the result of detection from the NEO-M8N GPS sensor on the coordinates of the portable neonatal incubator position displayed via the application while Figure 13(b) is the result of detection from the smartphone on the coordinates of the position of the person carrying the incubator. This test aimed to determine the accuracy of the NEO-M8N GPS sensor in reading specified points. In this test, five samples from different locations of the path were taken, as shown in Figure 9.



(a) (b)

Figure 13. Results of latitude and longitude position coordinate readings of the portable neonate incubator (a) monitoring application and (b) smartphone

Tables 1 and 2 showed a difference in distance between the NEO-M8M GPS sensor point and the smartphone GPS sensor by 5-12 meters. This disparity arose because the longitude and latitude points generated on Google Maps came from smartphone GPS sensors equipped with additional Wi-Fi scanning and Bluetooth scanning capabilities to enhance the accuracy of detecting coordinate points. However, the NEO-M8N GPS sensor could only detect signals from satellites, making it susceptible to GPS Bounce and hindering the reception of satellite signals properly.

Table 1. Testing the accuracy of the NEO-M8M GPS sensor with a reference smartphone GPS at the starting position (Campus D) towards the neonatal incubator

Location	GPS sensor		Smartphone GPS		Error% Latitude	Error% Longitude	Distance difference (m)
	Latitude	Longitude	Latitude	Longitude			
1	-6.36878	106.83382	-6.36871	106.83385	0.00110	0.00003	7.9
2	-6.35647	106.83197	-6.35639	106.83186	0.00126	0.00010	8.6
3	-6.35507	106.84822	-6.35383	106.83842	0.01952	0.00917	5.4
4	-6.35512	106.84840	-6.35514	106.84822	0.00031	0.00017	5.7
5	-6.34593	106.85357	-6.34627	106.85335	0.00536	0.00021	9.4

Table 2. Testing the accuracy of the NEO-M8M GPS sensor with a reference smartphone GPS at the destination position of the neonate incubator (Campus F6)

Location	GPS sensor		Smartphone GPS		Error% Latitude	Error% Longitude	Distance difference (m)
	Latitude	Longitude	Latitude	Longitude			
1	-6.36880	106.83380	-6.36871	106.83385	0.00141	0.00005	9.0
2	-6.35646	106.83195	-6.35639	106.83186	0.00110	0.00008	12.0
3	-6.35485	106.84166	-6.35383	106.83842	0.01605	0.00303	4.5
4	-6.35519	106.84878	-6.35514	106.84822	0.00079	0.00052	5.7
5	-6.34593	106.85357	-6.34627	106.85335	0.00536	0.00021	5.2

4.1.3. DHT21 sensor accuracy testing

Tests were also conducted to compare temperature and humidity results read by the DHT21 sensor with a digital thermometer, as shown in Figure 14. According to Table 3, the temperature data error value was 6.64% with a digital thermometer. This implied that the accuracy of the DHT21 temperature sensor was 93.36%. Table 4, the error value of each humidity data was 5.75% with a digital thermometer. This suggested that the accuracy of the DHT21 humidity sensor was 94.25%.

Figure 14. Temperature and humidity values of DHT21 sensor and digital thermometer in neonate incubator room

Table 3. Testing the accuracy of the DHT21 sensor with reference digital thermometer

Point	Calibrated digital thermometer (°C)	DHT21 temperature (°C)	Error (%)
1	31.60	35.20	11.39
2	33.30	36.50	9.61
3	34.20	36.70	7.31
4	36.80	38.30	4.08
5	36.60	36.30	0.82
		Average % error	6.64

Table 4. Testing the accuracy of the DHT21 (humidity) sensor with reference digital thermometer

No	Calibrated digital thermometer (%)	DHT21 Humidity {%)	Error (%)
1	65.00	59.30	8.77
2	58.00	54.70	5.69
3	57.00	54.70	4.04
4	52.00	50.40	3.08
5	50.00	53.60	7.20
		Average % error	5.75

4.1.4. Neonate body temperature sensor testing

The test aimed to assess the application's precision in detecting the body temperature of neonates while inside the incubator. This evaluation consisted of a one-week-old neonate placed in an incubator, without the portable incubator being transported, as shown in Figure 15. Figure 15(a) is a one-week-old neonate placed in an incubator, on the body of this neonate a DS18B20 sensor is attached to measure its body temperature, without moving the portable incubator and Figure 15(b) is the result of reading the body temperature value of the neonate in the portable neonatal incubator which can be seen on the application and LCD. Table 5 is a table of test results and calculations of the accuracy of the DS18B20 sensor in reading neonate body temperature. The results of the analysis by comparing with the results of the HTC-2 Hygrometer showed that the accuracy level of the DS18B20 temperature sensor readings had a value of 91.79%.

(a) (b)

Figure 15. Testing the DS18B20 sensor in the neonate incubator room (a) a one-week-old newborn baby and (b) the temperature value on the heating application and the LCD of the portable neonate incubator

Table 5. Testing the accuracy of the DS18B20 sensor with reference HTC-2 Hygrometer

No	Calibrated HTC-2 Hygrometer (°C)	DS18B20 temperature (°C)	Error (%)
1	24.9	26.4	5.68
2	27.4	29.8	8.05
3	28.8	31.5	8.57
4	29.8	32.8	8.87
5	30.3	33.2	8.74
6	30.8	33.6	8.33
7	31.1	33.9	8.26
8	31.3	34.2	8.48
9	31.5	34.5	8.70
10	31.7	34.6	8.38
		Average % error	8.21

5. CONCLUSION

In conclusion, the implementation of the GPS-based portable neonate incubator system yielded several key findings. The monitoring application on the smartphone could consistently track the position coordinates, distance, and time of the portable neonate incubator's journey. Additionally, it could monitor the temperature and humidity of the incubator room, as well as the body temperature of the neonate. Specifically, the NEO-M8M GPS sensor showed a distance error ranging from 5 to 12 meters. The DHT21 sensor showed a 93.36% accuracy in measuring the temperature and humidity of the neonate incubator room, while the DS18B20 sensor attained a temperature accuracy of 91.79% in measuring the neonate's body temperature. This GPS-based portable neonate incubator, weighing approximately 5.8 kg, was versatile, operating on either AC or DC power sources. Furthermore, it represented an innovative advancement in neonate incubator health equipment, effectively preventing neonatal deaths during transportation to the hospital and expediting the tracking of the portable neonate incubator's coordinate position in the event of theft.

For future development, a calibration test at the Health Facility Safety Center (BPFK) was conducted to ensure its feasibility, enhancing the safety and security of neonates in the incubator. This system could be used in Independent Midwife Practices or Puskesmas in Indonesia that lack neonate incubator facilities or during emergencies. To enhance the accuracy of distance readings from the Neo-M8N GPS sensor, a sampling process was implemented in order to obtain the average of each reading.

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