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# Portable Neonatal Incubator Monitoring and Control System: Integration of IoT Communication and Control Technology

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**Abstract**

Neonatal incubator is a medical equipment that is very much needed when there is a premature/critical neonate who will be referred to the hospital. However, the current baby incubator is large in size, making it difficult to transport to referral hospitals in secluded places. To address this challenge, a portable neonatal incubator has been designed with a temperature and humidity controller; monitor the position coordinates, distance, route time of the portable neonatal incubator; and alerts via brief messages/SMS; and A tote bag to facilitate transportation by medical personnel. The test results demonstrate that the DHT21 sensor control system can control temperature with yielding a computation accuracy of 96.65% and humidity accuracy of 95.67%. The portable neonatal incubator system effectively monitors the location coordinates of the position, distance, route time assessed based on GPS coordinates with an average positional deviation computation of 10.18 meters. The SIM7600CE GSM module transmits an alert to the smartphone when the portable neonatal incubator is stops moving for 1 minute so that if something suspicious occurs during the transportation process to the hospital, it can be handled immediately to avoid potential death or loss of the neonate. Further research needs to improve the battery life as a DC power source to ensure long-lasting performance.

**Keywords:** GPS, Portable Neonatal Incubator, Relative Humidity, SMS, Temperature

# 1 Introduction

Prematurity remains a major health issue worldwide. According to the 2011 Indonesian Demographic Health Survey, 350,000 babies are born prematurely each year in Indonesia. Indonesia ranks 5th in the world with the highest number of premature births, with 675,700 premature births each year and 10.2% of all births are born with low birth weight (LBW) [8]. Based on data from the World Health Organization (WHO), around 15 million births worldwide each year are premature. More than one million of them die soon after birth [39]. Approximately 15 million and one million premature babies die each year [21] due to the survival gap between high and low income countries. In this case, premature babies are born before 34 weeks of gestation [19]. According to UNICEF, premature births in Indonesia are ranked fifth with 13,370 premature babies on January 18, 2018 [38]. Many premature babies die due to the lack of simple care and adequate equipment, such as incubators [33].

An incubator is a medical care device for premature babies that provides warmth, humidity, and oxygen according to the needs of newborns under controlled conditions [16]. Neonatal mortality rates are also influenced by various factors, with preterm birth being one of the most significant factors. Differences between remote and urban areas, especially in access to health facilities and health workers, can affect the occurrence of preterm birth [35]. An important medical device to keep the temperature of the neonate stable is the incubator. This tool provides a controlled environment that helps prevent hypothermia and supports the overall health of premature or sick neonates. Baby incubators are very important to maintain the body temperature of newborns, especially for premature babies.

Several researchers have designed portable incubators, such as: Researchers [27] with the Grashof Incubator is a baby warmer with a natural convection system and natural circulation. This product is one of the community service programs since 2012, running well, because it has been proven to work to warm the baby's cabin as needed, namely the range of 33 °C - 35 °C. Research [42] temperature measurement method using DS18B20 sensor to measure temperature and DHT22 sensor to determine the temperature stability point in the baby cabin and to determine the characteristics of temperature changes in the incubator following the ambient temperature. Data collection was carried out at ambient temperature variations of 25 °C - 30 °C and <25 °C in several conditions, 2x25 Watt and 2x40 Watt heating lamps, and the use of thermostats. The test results stated that the level of temperature stability in the baby cabin was highly dependent on the ambient temperature. Researchers [28] stated that neonatal incubators should be designed to produce room temperature conditions between 34 °C and 37 °C, mimicking the thermal environment of the uterus to support fragile thermoregulation in premature or sick newborns. Research [40] has produced a premature baby incubator that has a high level of sensitivity, one of which is to environmental temperature and humidity with temperature stability at 36 °C and humidity at an RH value of 80% - 60% in the incubator room and the temperature reaches a steady level at 218 seconds in the prototype test of babies without load. The infant incubator system [20] automatically turns the fan and/or heater on or off according to the normal range of temperature and humidity in the incubator. The normal temperature limit used is 33 °C to 35 °C. While the normal humidity limit in the incubator used is between 40% and 60%.

Other studies have implemented remote monitoring of neonatal incubators using cellular networks, such as: Researchers [15] integrated cellular networks into a health service monitoring system, particularly in the development of incubators. This system utilizes real-time data transmission to monitor incubator conditions and send alerts to health care providers. Researchers [22] designed a baby incubator temperature and humidity monitoring system via a WiFi network using a temperature sensor and DHT 22 which will be sent via WiFi ESP32 and the values obtained will be displayed on the display to make it easier for nurses to monitor premature babies so that there is no negligence. Research [34] designed an embedded device that monitors parameters such as the baby's pulse, temperature, humidity and light inside the incubator with an android application or a hospital web page via IoT, so that appropriate actions can be taken beforehand, to protect the environment in the incubator and ensure safety for the baby's life. The study [32] presents a proposal for a system for a baby incubator based on the use of temperature and humidity sensors, and a set of weight sensors, which allow us to monitor the progress of the baby. The system is connected to a central network based on Long Range Networks (LoRa) that allows the registration of medical data in a database that allows the identification of the doctor, the display of the patient's evolution with a tablet and the introduction of new data by the doctor.

Based on several previous studies that have been mentioned, we have not found the development of a special baby incubator that can be brought when the baby is referred to the hospital. The idea for this research came about when we met with several midwives at the Independent Midwife Practice who assisted in the birth of babies. Midwives had difficulty in assisting the birth of premature/low birth weight babies who had to be immediately referred to the hospital. Independent Midwife Practice is an integral part of the health care system in Indonesia. Independent Midwife Practice plays an important role in providing comprehensive and quality health services to the community, especially the childbirth process [25], [12]. However, not all Independent Midwife Practices in Indonesia have portable neonatal incubators, so if there is a premature/critical newborn baby (neonate) it will take a long time to get to the hospital, this will have a bad impact on the neonate which can cause death.

In today's world, the proliferation of mobile phones as portable devices has produced many innovative systems that help our daily activities, especially tracking systems. This type of system often consists of a GPS (Global Positioning System) receiver, a microcontroller, and a modem that supports GSM (Global System for Mobile Communications) [3]. Some studies that use GPS and GSM as tracking devices such as Mobile applications use GPS and SMS services found on Android phones. The parent device sends a location request SMS to the child's device to get the child's location, then the child's device replies the GPS position to the parent device based on the request [2]. A passenger tracking system based on the Global Positioning System (GPS) and Global System for Mobile Communication (GSM) which tracks passengers using ticket numbers and displays the location on Google maps [9]. Closed loop control system to regulate temperature, relative humidity, light intensity using LED inside neonatal incubator and in risky situations is communicated to parents with alarm system and GSM technology [5]. [23] Created a device that can be tracked using GPS location, as well as a panic button on the device that alerts parents via a GSM module, asking for help. The parent's phone that can receive and make calls and send and receive SMS on the smart device via the GSM module is always connected to the device. A child monitoring system that can track children using the global positioning system (GPS) and global cellular communication system (GSM) technology [37], [29]. An Internet of Things (IoT) based Child Monitoring System, which will enable parents to monitor and detect their children's activities even when they are away from home. Various Sensors/Modules are installed on the child to detect every activity. All the data collected from the sensors/modules will be stored in the cloud and checked periodically. [36] describes a child tracking system that combines ESP32CAM, GPS location, and image capture functions. This system allows parents to monitor their children in real time.

In previous research [31], we have designed a neonatal incubator system with the ability to provide incubator information such as temperature, humidity and location coordinates via the internet network using a WiFi access point. Weighing around 5.8 kg, this incubator can use AC and DC voltage sources, and is equipped with a carrying case for easy transportation by midwives or medical personnel to referral hospitals. The weakness of this system is that a WiFi signal is needed as a communication medium so that the parents'/medical personnel's carrying the neonatal incubator must bring a smartphone whose number is registered on the ESP32 microcontroller module.

In this study, the ESP32 microprocessor module and the NEO-M8N GPS module were replaced with the Arduino MEGA 2560 microprocessor and Adafruit GPS Sensor shield and the SIM7600CE module was added complete with SMS facilities. With this SIM7600CE module, the portable neonatal incubator system no longer requires a WiFi access point for communication with parents/medical personnel. SMS sends information messages to the parents'/medical personnel's smartphones, so that they can see the condition of the newborn, the condition of the incubator and can track the coordinates of the incubator's location via the application on the parents'/medical personnel's smartphone, to avoid parents' anxiety about losing their baby on the way to the hospital.

The purpose of this study is to design, prototype and implement a Portable Neonatal Incubator Tracking System. Thus, parents/medical personnel can continue to monitor and track portable neonatal incubators that move on demand using smartphones and determine the estimated distance and time for the portable neonatal incubator to arrive at the referral hospital so as to prevent neonatal death/loss.

## 2 System Architecture and Control Principle

In this study, we propose a portable neonatal incubator based on GPS and GSM design consisting of three components, namely System architecture, hardware components, and firmware components. The system architecture describes the supporting components of the incubator system, namely the sensor, controller, and output components. The hardware design describes the incubator design and the position of the incubator controller system components. The firmware design describes the program architecture and the incubator controller system flow diagram and the data flow diagram describes the incubator controller data communication process.

### 2.1 Components Architecture

The portable neonate incubator comprised the portable incubator, a controller system, a cloud database system, and a tracking system that can be powered through AC power and DC UPS (Uninterruptible Power Supply) made from 18650 battery pack. The controller system integrated several input components such as incubator room temperature and humidity DHT21 sensor and incubator position coordinates Adafruit GPS (Global Positioning System) sensor shield. The controller used in this system is an Arduino Mega 2560 microcontroller stacked with a SIM7600CE cellular network shield to utilize 4G data credit and data plan for network connectivity. The output components controlled from Arduino Mega 2560 consist of a 2004 LCD (Liquid Crystal Display) and a peltier module, heater rods, DC fans which are connected via PWM (Pulse Width Modulation) module. For cloud databases, ThingSpeak was used for its services by providing multiple data fields for multiple variables being used in the system [18]. The system architecture described above can be seen in the following Figure 1.

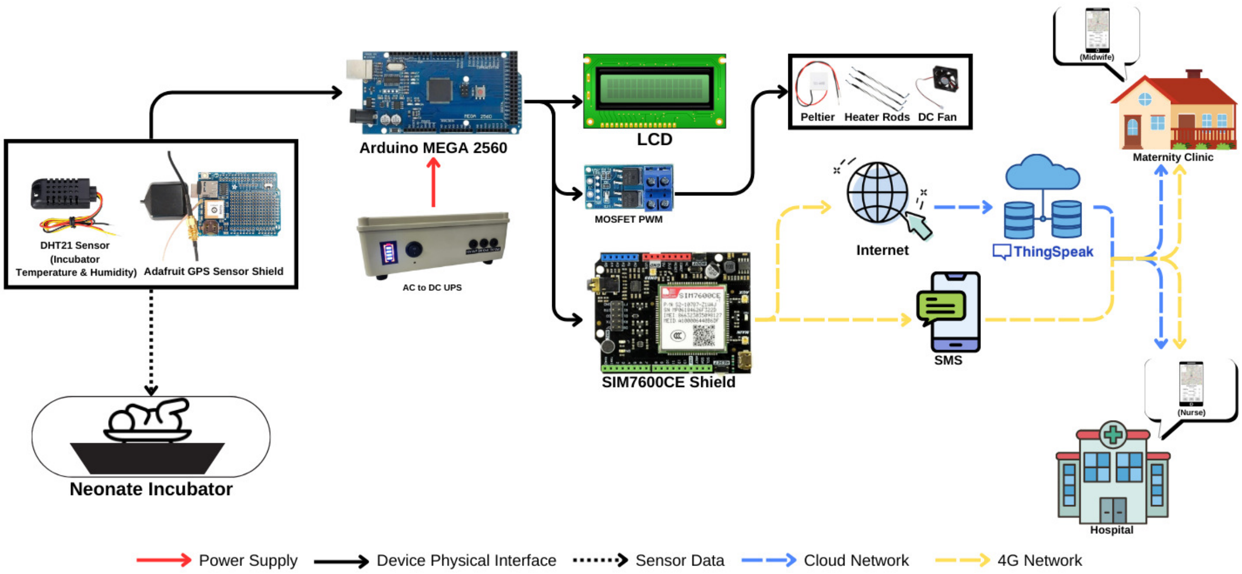


Figure 1: The components architecture of the portable neonatal incubator

### 2.2 Hardware Design

The portable neonatal incubator which was made of acrylic, designed with dimensions 66 × 30 × 34 cm3 and divided into three parts. The incubator part was used for neonatal beds, the container part was used for electrical components of the controller system, and the cover part. The container was designed with a sliding mechanism which will enter the bottom side of the incubator. Holes were made on the right and left side of the incubator part for the air circulation, as shown in Figure 2. For the design process of the placement of air holes, fan positions, heaters and coolers in the neonatal incubator, we use the help of solidwork software [17], [43]. The simulation results can be seen in Figure 3.

The input components used for the system consist of a DHT21 sensor to measure room temperature and humidity conditions inside of the incubator, with a pre-defined suitable condition ranging from 34 °C to 37 °C for temperature and 60% to 80% for relative humidity. An Adafruit GPS sensor shield was used to receive latitude and longitude coordinates from satellites which will be calculated to determine geographical location of the incubator. DC fans were used to help hot and cold air circulation created from heater rods and peltier module inside of the incubator.

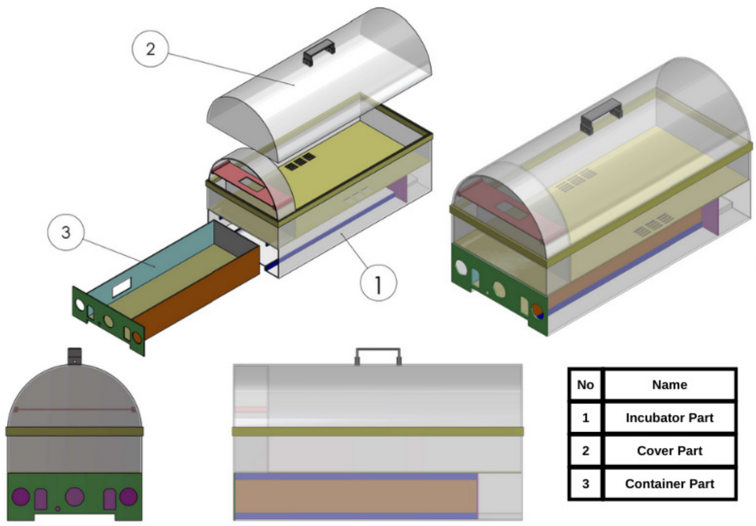


Figure 2: The physical design of the portable neonatal incubator

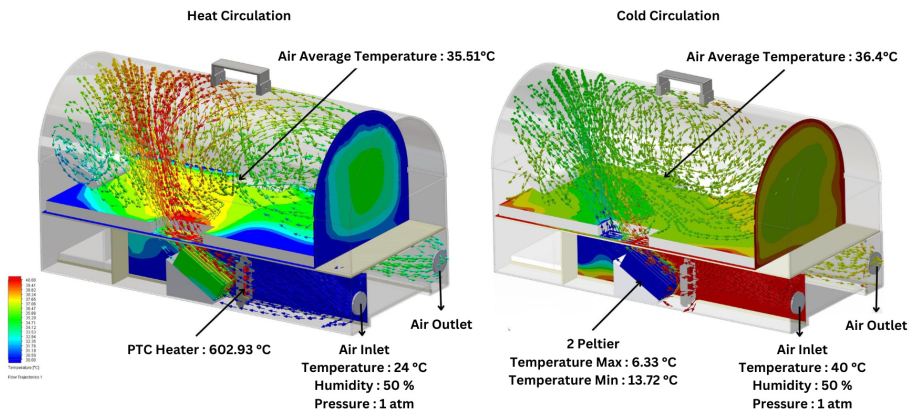


Figure 3: The simulated air circulation of the portable neonatal incubator

To assist peltier module heat dissipation, a waterblock system was used with liquid coolant as heat transfer medium into the radiator. The 2004 LCD module was used for on-site values tracking such as incubator temperature, relative humidity, and location condition. Components placement can be seen in Figure 4.

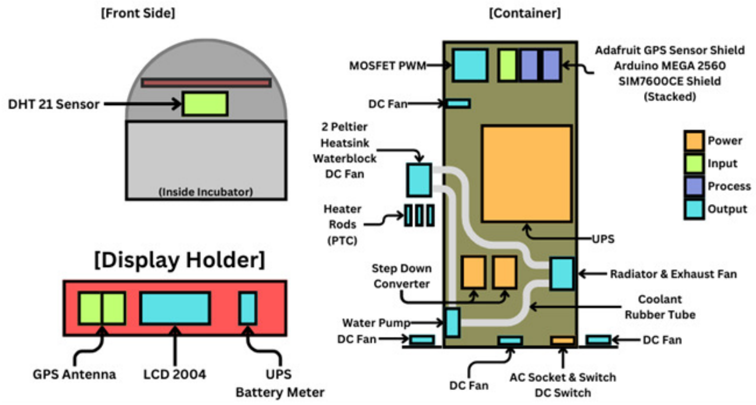


Figure 4: The components placement of the portable neonatal incubator

## 2.3 Firmware Design

The portable neonatal incubator based on GPS and GSM programmed with Arduino IDE, an open-source embedded system integrated development environment using a modified C programming language [26]. The Arduino Mega 2560 was programmed with Arduino IDE to monitor and control the portable incubator condition via several communication protocols including NMEA for GPS data [41], one-wire for incubator temperature and relative humidity data, $I^2C$ to display sensor data on LCD and serial AT command for 4G network connectivity. To adjust incubator condition with pre-programmed suitable condition, the output components are controlled via the PWM method using PWM pins of the Arduino Mega 2560. The ThingSpeak is being used to record sensor data based on time uploaded so the data can be used with other type tracking applications or systems via HTTP request using cellular network mobile data plan. SMS is also being used to monitor the incubator condition by an alert system without an internet dependency. The firmware architecture described above can be seen in Figure 5.

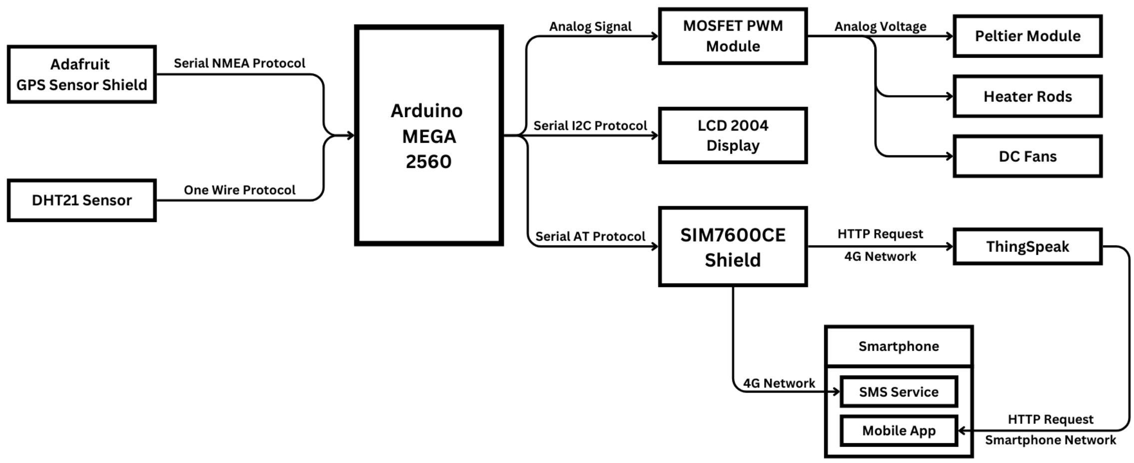


Figure 5: The firmware architecture of the portable neonatal incubator

During the initialization, each sensor, process, and output components are configured differently. DHT21 sensors are configured with GPIO (General Purpose Input Output) pins as an input to the microcontroller. The Adafruit GPS sensor shield is configured to communicate with the microcontroller as a transmitting serial device via RX-TX (receiver - transmitter) pins. For data display on the LCD, an $I^2C$ module is required to reduce the number of pins needed by configuring the microcontroller SDA (Serial Data) and SCL (Serial Clock) pins. To connect to the 4G and internet network, the microcontroller is configured as a transmitting serial device that sends data in the form of AT command to the SIM7600CE shield connected via RX-TX pins. With high power requirements of the output components, PWM modules are required as a bridge between the microcontroller and the components by configuring the GPIO pins that have the ability to generate PWM signals.

After initialization, the incubator condition is monitored by the controller system with DHT21 and Adafruit GPS sensor shield then registered the sensor data into variables which will be uploaded to ThingSpeak. When the data are registered to the ThingSpeak, the data then displayed on the 2004 LCD via microcontroller global variables and on the mobile application via HTTP request using cellular network mobile data plan. If the current incubator position is detected not moving or changing within 1 minute, an alert system will be triggered and the microcontroller will start counting fixed stop condition time and send an alert using the SMS service of 4G network into cellular numbers registered in the microcontroller during initialization. The timer of the alert system will be resetted to 0 after the incubator moves again. Figure 6 showed the designed flowchart of the portable neonatal incubator based on GPS and GSM.

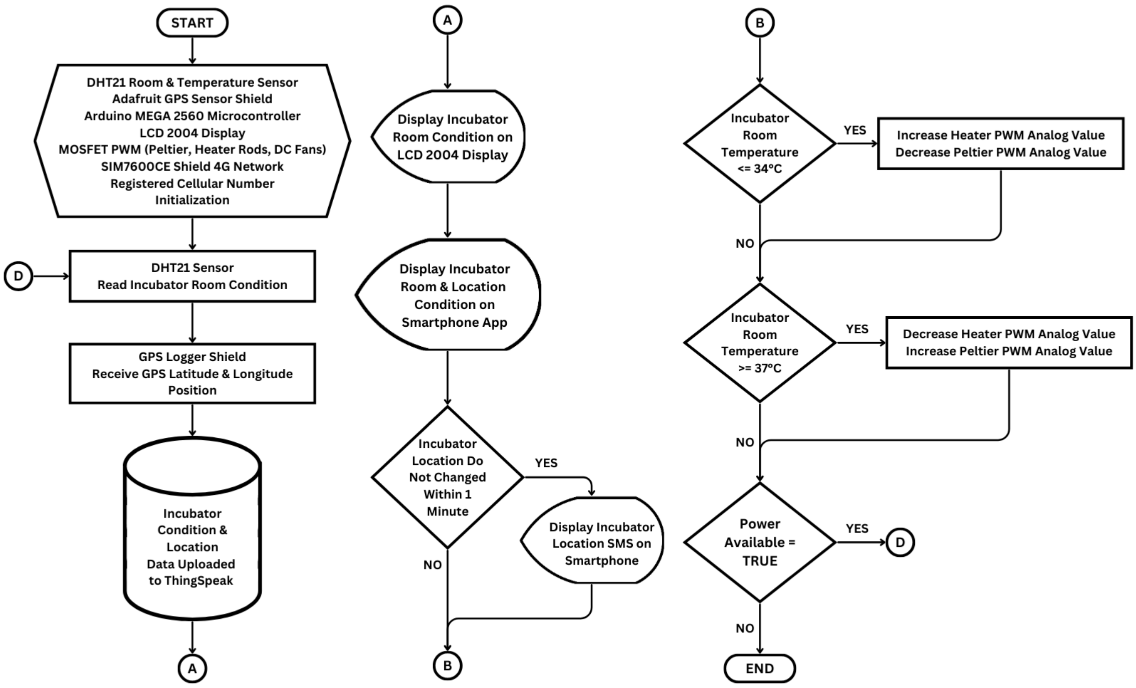


Figure 6: The flowchart of the portable neonatal incubator

## 2.4 Data Flow Diagram

There are two tracking applications used in this system. First tracking system used the mobile application developed in the previous research and the second tracking system used the SMS messenger available in the phone. Both of the tracking systems used cellular network connectivity to monitor the incubator conditions.

To upload the data, the Arduino Mega 2560 constructed an AT command which included the command, ThingSpeak URL (Uniform Resource Locator), its credentials, the sensor values and sent the complete command to the SIM7600CE module to upload the sensor values to ThingSpeak. The sensor values consist of incubator room condition values from the temperature and humidity DHT21 sensor and incubator location coordinates from the Adafruit GPS sensor shield were uploaded to ThingSpeak in body text format and combined the corresponding Write API Key of the destination channel with HTTP POST method using 4G data plan available on the SIM7600CE module. The sensor values will be registered at the ThingSpeak data fields in the form of a time-based graphical interface. When the new received coordinates are the same with the current coordinates or the distance between new received coordinates and current coordinates is less than 5 meters, a timer will start counting for 1 minute. After 1 minute elapsed and the coordinates or distance still less than 5 meters, the alert system programmed in the Arduino Mega 2560 will send an AT command which contain a command and SMS text that formatted with the sensor values and registered cellular number to the SIM7600CE module to send the SMS indicating the incubator is stuck in the traffic or encounters an unwanted occurrence.

In this Portable neonatal incubator based on GPS and GSM, the user entity could track incubator location with two methods. First the incubator can be tracked using the tracking application in real time and the second method incubator can be tracked during distress situations such as traffic jams or other unwanted occurrences by accessing the Google Maps URL stated at the alert SMS. When using the first method, the application sends HTTP GET requests in JSON (JavaScript Object Notation) text format to the ThingSpeak services requesting incubator condition data then displays the data with the internet network provided on the phone. The user could track the incubator condition in the tracking application [30] and in the SMS messenger, as shown in Figure 7.

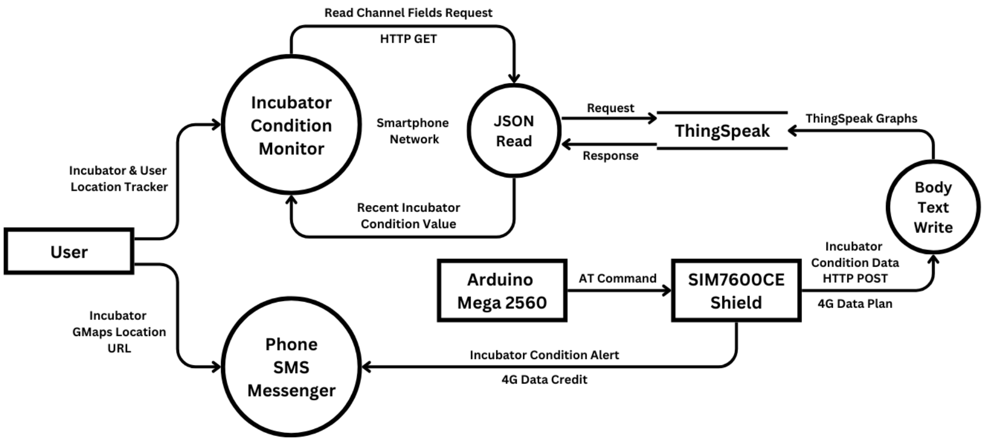


Figure 7: The DFD between portable neonatal incubator and application

### 2.5 GPS Sensor Deviation Distance

Great-circle distance, a shortest distance between two points on the surface of a sphere, such as earth, provides an accurate representation of distance between geographic locations used for aviation, navigation, and geospatial analysis [7], [4]. To calculate the distance between two points, a formula named Haversine formula was used by calculating the distance between two points regardless the depth of a valley and the height of a hill on the earth's surface [1]. The Haversine formula calculates the great-circle distance between two points on the earth's spherical surface by considering the earth radius as R, approximately 6.371 kilometers to account for its spherical shape. The two points are represented in spherical coordinates latitude and longitude with the first point as ($Lat_1$ and $Long_1$) and the second point ($Lat_2$ and $Long_2$) [24]. The latitude and longitude coordinates must be converted from degrees-minutes-second or decimal degrees format into radians to use the trigonometric functions [11]. Mathematically, the Haversine formula used to find great-circle distance is expressed as:

$$d = 2 \cdot R \cdot sin^{-1}\left(\sqrt{\left(sin^2\left(\frac{\Delta Lat}{2}\right)\right) + \left(cos(Lat_1) \cdot cos(Lat_2) \cdot sin^2\left(\frac{\Delta Long}{2}\right)\right)}\right) \quad (1)$$

Where d is the great-circle distance between two coordinates in a meter unit. R = radius of earth (≈ 6.371.000 meters). ΔLat = difference of two latitude coordinates ($Lat_2$ - $Lat_1$) and ΔLong = difference of two longitude coordinates ($Long_2$ - $Long_1$), with the unit of each variable in radians. The [$Lat_2$, $Long_2$] used as target position coordinates and [$Lat_1$, $Long_1$] as current position coordinates.

### 2.6 One Wire Sensor Data Acquisition

To read DHT21 (AM2301) sensor data, one-wire protocol is used as a communication standard that facilitates data transfer between a master device and one or more slave devices using a single data line, along with a ground reference [6]. Data exchange occurs via precise timing of voltage level changes, with each bit encoded using specific durations for logic high and low states. The one-wire protocol is highly efficient for low-speed, low-power applications, such as temperature sensors, memory devices, and identification chips [10]. Its simplicity, scalability, and minimal wiring requirements make it ideal for resource-constrained environments. The internal microcontroller of DHT21 manages the communication, by handling the timing and formatting of the 40-bit data packet sent to the master device (Arduino Mega 2560). Mathematically, the extraction of DHT21 temperature and relative humidity values using Arduino IDE is explained as follows:

$$Relative\ Humidity\ (\%) = \frac{((HighByte_{\mathrm{RH}})_{10} \cdot 2^8) + ((LowByte_{\mathrm{RH}})_{10} \cdot 2^0)}{10} \quad (2)$$

$$Temperature\ (^\circ C) = \frac{((HighByte_{\mathrm{Temp}})_{10} \cdot 2^8) + ((LowByte_{\mathrm{Temp}})_{10} \cdot 2^0)}{10} \quad (3)$$

With the changing condition of the incubator room sensed by DHT21 sensor, both cooling and heating systems would work according to the incubator room temperature condition, with pre-programmed requirements of suitable temperature condition for neonatal is 34 °C until 37 °C. The controller system will shut off and adjust analog signals of the cooling system which consist of a peltier module and a water block contraption or the heating system which consist of heater rods and DC fans. By adjusting the output components, the suitable temperature condition for neonates can be reached.

## 3 Results

Portable neonatal incubator based on GPS and GSM was designed to facilitate mobility during emergency situations which can be used by medical personnel to be referred to the hospital. The tracking application is designed to help medical personnel track the condition of the incubator during the transportation process from the birthing house to the hospital. The prototype of the portable neonatal incubator based on GPS and GSM were shown in Figure 8. This portable neonatal incubator can operate using either DC or AC power which are shown in Figure 9.

Figure 8: The protototype of portable neonatal incubator with the carrying bag

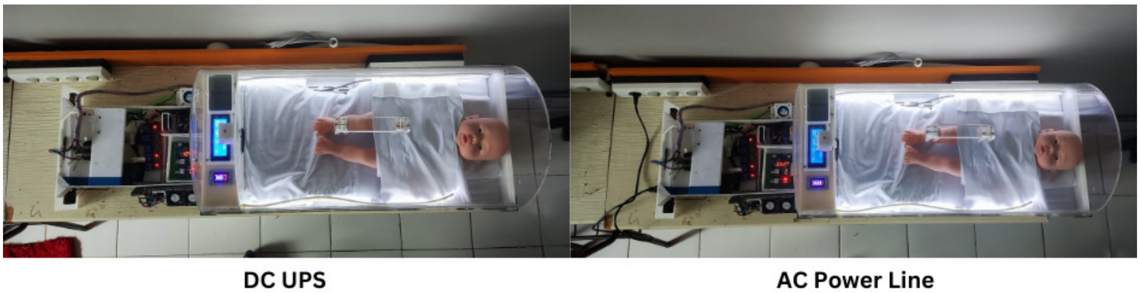


Figure 9: The operation of the prototype using DC and AC power

Tests were also carried out to determine the errors produced from the DHT21 sensor. The measured variable includes incubator room temperature and relative humidity measured using a DHT21 sensor and a calibrated digital thermometer. Measured values from digital thermometer then used as a reference value to determine the errors produced from the DHT21 sensor. Calibrated digital thermometer was used as a reference sensor device because of known accuracy of ± 1 °C for temperature reading and ± 5 % for relative humidity reading. The measured temperature and relative humidity reading errors can be seen in Table 1 and Table 2 .

GPS tracking capabilities were tested to observe the functionality of the Adafruit GPS sensor shield. Tests were conducted between two locations with the initial location being at Bidan Jeanne (Kelapa Dua, Depok, Indonesia) and the destination location being at Bidan Ismi Santi (Kelapa Dua, Depok, Indonesia). To measure the GPS tracking capabilities, five checkpoints were reached to sample and record the received GPS coordinates of incubator current location which can be seen in Table 3. Google Maps services [14] are used to visualize the route and the stop checkpoints passed between both locations with a total travel distance 1.2 km which are shown in Figure 10.

Additional tests were conducted to determine the errors produced by the Adafruit GPS sensor shield. To measure the errors of the sensor, another sample and record of received GPS coordinates was done by using built-in GPS of a smartphone located on-site with the incubator. With record of coordinates from smartphone GPS as a reference value, the errors of the sensor can be determined which can be seen in Table 4. To calculate error margin or deviation distance of the Adafruit GPS sensor shield in this study, the Haversine formula was used using the smartphone GPS coordinates as target position and Adafruit GPS sensor shield coordinates as deviation position.

Built-in GPS smartphone was used as a reference device because the coordinates information received is not only from satellites, but also with several information of wireless signals. The signals being used to generate high accuracy of positioning system are WiFi access point, cellular network towers, and other sensor data such as accelerometer, gyroscope, and barometer integrated inside the smartphone [13]. With the smartphone coordinates received from several methods, the errors of the Adafruit GPS sensor shield that only used satellites as source of information can be calculated. The errors can be produced because the Adafruit GPS sensor shield could experience phenomena such as reflecting signals around trees or buildings and enclosed space resulting in a high clustered satellite at

Table 1: The errors of the DHT21 sensor with reference temperature values from a digital thermometer.

| No | DHT21 (°C) | Calibrated Digital Thermometer (°C) | Temperature Difference (°C) | Error (%) | Accuracy (%) |
|---|---|---|---|---|---|
| 1 | 32.90 | 31.50 | 1.40 | 4.44 | 95.56 |
| 2 | 36.40 | 35.30 | 1.10 | 3.12 | 96.88 |
| 3 | 39.90 | 38.10 | 1.80 | 4.72 | 95.28 |
| 4 | 39.50 | 38.00 | 1.50 | 3.95 | 96.05 |
| 5 | 36.80 | 37.00 | 0.20 | 0.54 | 99.46 |
| Mean | | | 1.12 | 3.35 | 96.65 |

Table 2: The errors of the DHT21 sensor with reference relative humidity values from a digital thermometer.

| No | DHT21 (RH%) | Calibrated Digital Thermometer (RH%) | Relative Humidity Difference (RH%) | Error (%) | Accuracy (%) |
|---|---|---|---|---|---|
| 1 | 58.90 | 55.50 | 3.40 | 6.13 | 93.87 |
| 2 | 53.20 | 52.10 | 1.10 | 2.11 | 97.89 |
| 3 | 41.70 | 39.50 | 2.20 | 5.57 | 94.43 |
| 4 | 40.20 | 38.70 | 1.50 | 3.88 | 96.12 |
| 5 | 41.90 | 40.30 | 1.60 | 3.97 | 96.03 |
| Mean | | | 1.96 | 4.33 | 95.67 |


Figure 10: GPS location tracking visualized

one position [18].

The current studies findings indicate that Adafruit GPS sensor shield provide more error margin compared to the reported in previous studies. In the current study, the mean error margin provided was found to be ± 2 to 3 meters more than the previous study. Additionally, the current Adafruit GPS sensor shield was demonstrated at roads with high concentration buildings of urban areas with distance between the opposite buildings ± 6 meters while the Neo-M8N GPS sensor was demonstrated at main city roads with wider distance between the opposite buildings. With high concentration of building surrounding roads between first and last location, the Adafruit GPS sensor shield experiences phenomena such as reflecting signals.

Table 3: The initial, stop, and destination checkpoints with its coordinates.

| Location | Adafruit GPS Sensor Shield (Decimal Degrees) | | Smartphone GPS (Decimal Degrees) | | Location | Note |
|---|---|---|---|---|---|---|
| | Latitude | Longitude | Latitude | Longitude | | |
| 1 | -6.360375 | 106.843990 | -6.360330 | 106.843970 | Bidan Jeanne | Initial |
| 2 | -6.361317 | 106.843040 | -6.361290 | 106.842900 | Jl. Kelapa Dua Raya No. 47-45 | Stop 1 |
| 3 | -6.362483 | 106.843090 | -6.362520 | 106.842980 | Jl. Rtm No.12 | Stop 2 |
| 4 | -6.366412 | 106.843240 | -6.366350 | 106.843270 | Jl. H. Rijin 143-144 | Stop 3 |
| 5 | -6.365710 | 106.846320 | -6.365630 | 106.846340 | Bidan Ismi Santi | Destination |

Table 4: The errors of the Adafruit GPS sensor shield with a reference coordinates from smartphone GPS located on-site with the portable neonatal incubator.

| Location | Adafruit GPS Sensor Shield (Decimal Degrees) | | Smartphone GPS (Decimal Degrees) | | Error Margin (Deviation Distance - m) |
|---|---|---|---|---|---|
| | Latitude | Longitude | Latitude | Longitude | |
| 1 | -6.360375 | 106.843990 | -6.360330 | 106.843970 | 5.47 |
| 2 | -6.361317 | 106.843040 | -6.361290 | 106.842900 | 15.76 |
| 3 | -6.362483 | 106.843090 | -6.362520 | 106.842980 | 12.83 |
| 4 | -6.366412 | 106.843240 | -6.366350 | 106.843270 | 7.65 |
| 5 | -6.365710 | 106.846320 | -6.365630 | 106.846340 | 9.17 |
| Mean Error Margin | | | | | 10.18 |

Alert system test conducted to measure interval time between each alert SMS. SMS will be sent when the incubator was not moving or measured distance between current coordinates and received new coordinates still less than 5 meters for more than 1 minute. A smartphone with a registered number is used to receive the alert SMS, which then interval time between each SMS can be measured as seen in Table 5. Figure 11 shows the SMS results sent by the portable neonatal incubator when it stops for more than 1 minute at the 5 locations in Figure 10.

Table 5: The interval time between alert SMSes of the portable neonatal incubator for not moving more than 1 minute.

| Location | Adafruit GPS Sensor Shield (Decimal Degrees) | | Elapsed Time of the Incubator Received on First SMS | Elapsed Time of the Incubator Received on Second SMS | Interval Time between SMS |
|---|---|---|---|---|---|
| | Latitude | Longitude | | | |
| 1 | -6.360375 | 106.843990 | 00 m 20 s | 01 m 23 s | 01 m 03 s |
| 2 | -6.361317 | 106.843040 | 20 m 30 s | 21 m 34 s | 01 m 04 s |
| 3 | -6.362483 | 106.843090 | 06 m 42 s | 07 m 46 s | 01 m 04 s |
| 4 | -6.366412 | 106.843240 | 02 m 27 s | 03 m 31 s | 01 m 04 s |
| 5 | -6.365710 | 106.846320 | 05 m 36 s | 06 m 39 s | 01 m 03 s |
| Mean Interval Time for the SMS to be Received after Incubator not Changing Location (s) | | | | | 01 m 04 s |

The usage of cellular networks as communication services can become an alternative to WiFi networks which are linear with the main objective of the portable neonatal incubator to facilitate mobility for neonatal transportation. With cellular networks, the incubator would not need to be prepared with a device that provides WiFi networks such as MiFi device or smartphone which by activating the WiFi hotspot can drain the smartphone battery significantly. The cellular networks used in this system only need to be prepared with data plan and data credit from an application correspondence with the SIM (Subscriber Identity Module) card provider. In Figure 12, the portable neonatal incubator which was prepared with the controller and tracking system, on the way transported by motorcycle from Bidan Jeanne to Bidan Ismi Santi, was placed into a specific-made bag between two officers.


Figure 11: Received SMS from the portable neonatal incubator alert system with Google Maps web page from accessing the URL stated on the SMS


Figure 12: Portable neonatal incubator test

## 4 Conclusion

In this research, the implementation of a portable neonatal incubator monitoring and control system using smartphone communication technology has been developed and evaluated. By using a 4G communication network, the system can consistently monitor and control the temperature, relative humidity, position coordinates, distance, travel time of the portable neonatal incubator without requiring WiFi network connectivity. The system can operate with AC or DC power sources.

The DHT21 sensor measured an average temperature deviation computation of 1.12 °C and an average relative humidity of 1.96%, yielding a computation accuracy of 96.65% for temperature readings and 95.67% for relative humidity readings. The Adafruit Global Positioning System (GPS) sensor enclosure detected a coverage computation of 5.47 to 15.76 meters with an average positional deviation computation of 10.18 meters. The portable neonatal incubator system successfully transfers data with a mean time of 01 m 04 s in the form of temperature, relative humidity and location coordinates of position, distance, route time measured using GPS coordinates through the GSM SIM7600CE module to a smartphone when the portable neonatal incubator is motionless for 1 minute with the aim that if something suspicious occurs during the transportation process to the hospital, it can be handled immediately to avoid potential death or loss of the neonate.

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### Author contributions

The authors contributed equally to this work.

### Conflict of interest

The authors declare no conflict of interest.

## References

[1] Agramanisti Azdy, R.; Darnis, F. (2020). Use of Haversine Formula in Finding Distance Between Temporary Shelter and Waste End Processing Sites, *Journal of Physics: Conference Series*, DOI: 10.1088/1742-6596/1500/1/012104, 1500(1), 012104, 2020.

[2] Al-Mazloum, A.; Omer, E.; Abdullah, M.F.A. (2014). GPS and SMS-Based Child Tracking System Using Smart Phone, *World Academy of Science, Engineering and Technology International Journal of Electronics and Communication Engineering*, DOI: https://doi.org/10.5281/zenodo.1335994, 7(2), 2014.

[3] Al Rashed, M.A.; Oumar, O.A.; Singh, D. (2013). A real time GSM/GPS based tracking system based on GSM mobile phone, In *Second International Conference on Future Generation Communication Technologies (FGCT 2013)*, IEEE, DOI: 10.1109/FGCT.2013.6767186, 65–68, 2013.

[4] Anisya; Swara, G.Y. (2017). Implementation Of Haversine Formula And Best First Search Method In Searching Of Tsunami Evacuation Route, *IOP Conference Series: Earth and Environmental Science*, DOI: 10.1088/1755-1315/97/1/012004, 97(1), 012004, 2017.

[5] Atul W. Kale; Ajay H. Raghuvanshi; Pranit S. Narule; Pooja S. Gawatre; Shilpa B. Surwade. (2018). Arduino Based Baby Incubator Using GSM Technology, *International Research Journal of Engineering and Technology (IRJET)*, 5(4), 462–465, 2018.

[6] Ayyagari, R.S.; Joshi, S.; Patil, B.; Boddhapu, M.T.; Inc, T.I. (2013). Single Wire Communications Interface and Protocol, *Google Patents*, US20150074306A1, 2018.

[7] Bansal, R. (2021). Deriving and testing the great circle theory, *International Journal of Statistics and Applied Mathematics*, DOI: https://doi.org/10.22271/maths.2021.v6.i5a.722, 6(5), 16–24, 2021.

[8] Bernie, E.M. (2021). Growth and Development in Preterm Infants: What is The Long-Term Risk?, *Medise. Amerta Nutr*, DOI: 10.20473/amnt.V5i1SP.2021.27-33, 27–33, 2021.

[9] Dalip; Vijay Kumar. (2014). GPS and GSM based Passenger Tracking System, *International Journal of Computer Applications*, DOI: 10.5120/17499-8039, 100(2), 30–34, 2014.

[10] Dudak, J.; Tanuska, P.; Gaspar, G.; Fabo, P. (2018). ARM-Based Universal 1-Wire Module Solution, *Journal of Sensors*, DOI: https://doi.org/10.1155/2018/5268247, 2018(1), 1–16, 2018.

[11] Heliza Rahmania Hatta; Muhammad Hadi Suroso; Indah Fitri Astuti; Dyna Marisa Khairina; Septya Maharani. (2021). Application of Haversine Formula in Education Game 'Landmark Nusantara', *Series: Advances in engineering research, Proceedings of the 2nd Borobudur International Symposium on Science and Technology (BIS-STE 2020)*, DOI: 10.2991/aer.k.210810.039, 234–237, 2021.

[12] Hidayah, K.N.; Samuri, S. (2022). Juridical Review of Midwife Practices and Authorities in Providing Midwifery Services Based on Presidential Regulation No. 82 of 2018 concerning Health Insurance, *Jurnal Hukum Kesehatan*, DOI: https://doi.org/10.24167/shk.v8i2.5156, 8(2), 156–163, 2022.

[13] Huang, Z.; Xuand,L.; Lin, Y. (2020). Multi-Stage Pedestrian Positioning Using Filtered WiFi Scanner Data in an Urban Road, *Environment. Sensors*, DOI: https://doi.org/10.3390/s20113259, 20(11), 3259, 2020.

[14] Ibrahim, O.A.; Mohsen, K. J. (2014). Design and implementation an online location based services using Google Maps for android mobile, *International Journal of Computer Networks and Communications Security*, 2(3), 113–118, 2014.

[15] Irmansyah, M.; Efrizon, E.; Madona, E.; Anggara N. (2021). Monitoring on Portable Baby Incubator Based on Microcontroller and Notification Using Short Message Service (SMS), *Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics*, DOI: 10.35882/ijeeemi.v3i4.3, 3(4), 140–147, 2021.

[16] Janney, B.J.; Krishnakumar, S.; Anushree, P.B.; Rayshma, V.; Suresh, S. (2018). Design of Mobile Infant Incubator with Comforting Pillow, *International Journal of Engineering and Technology (UAE)*, DOI: 10.14419/ijet.v7i2.25.12353, 7(2), 6–9, 2018.

[17] Kurowski, P.M. (2022). *Thermal analysis with SOLIDWORKS simulation 2022 and Flow Simulation*, SDC Publications, 2022.

[18] Kusuma, H.A.; Anjasmara, R.; Suhendra, T.; Yunianto, H.; Nugraha, S. (2020). An IoT Based Coastal Weather and Air Quality Monitoring Using GSM Technology, *Journal of Physics: Conference Series*, DOI: 10.1088/1742-6596/1501/1/012004, 1501(012004), 1–10, 2020.

[19] Kvalvik, L.G.; Wilcox, A.J.; Skjærven, R.; Østbye, T.; Harmon, Q.E. (2020). Term Complications and Subsequent Risk of Preterm Birth: Registry Based Study, *The BMJ*, DOI: https://doi.org/10.1136/bmj.m1007, 369, 2020.

[20] Latif, A.; Widodo, H.A.; Atmoko, R.A.; Phong, T.N.; Helmy, E. (2021). Temperature and humidity controlling system for baby incubator, *Journal of Robotics and Control (JRC)*, DOI: 10.18196/jrc.2376, 2(3), 2376, 2021.

[21] Lawn, J.E.; Davidge, R.; Paul, V.; Von Xylander, S.; De Graft Johnson, J.; Costello, A.; Kinney, M.; Segre, J.; Molyneux, E. (2013). Born Too Soon: Care for the preterm baby, *Reproductive Health*, DOI: https://doi.org/10.1186/1742-4755-10-S1-S5, 10(1), 5, 2013.

[22] Luthfiyah, S.; Kristya, F.; Wisana, I.D.G.H.; Thaseen, M. (2021). Baby incubator monitoring center for temperature and humidity using wifi network, *Journal of Electronics, Electromedical Engineering, and Medical Informatics*, DOI: 10.35882/jeeemi.v3i1.2, 3(1), 8–13, 2021.

[23] Manjunatha, N.; Jayashree, H.M.; Komal, N.; Nayana, K. (2020). IoT Based Smart Gadget for Child Safety and Tracking, *International Journal of Research in Engineering, Science and Management*, 3(6), 301–305, 2020.

[24] Muhammad, N.; Devi, R. (2023). Implementation Of Teacher Presence System Using Mobile-Based Geofencing & Haversine Formula Methods, *Applied Technology and Computing Science Journal*, DOI: https://doi.org/10.33086/atcsj.v6i1.4119, 6(1), 31–40, 2023.

[25] Nugraheni, G.; Nurdiana, A. (2020). The Assessment on Medical and Non-Medical Device Supply at Independent Midwifery Practices, *Jurnal Ilmu dan Teknologi Kesehatan*, 8(1), 47–63, 2020.

[26] Patton, E.W.; Tissenbaum, M.; Harunani, F. (2019). *MIT app inventor: objectives, design, and development*, Springer Singapore, 2019.

[27] Raldi Artono Koestoer; Ibnu Roihan; Alfredo Dwi Andrianto. (2018). Product Design, Prototyping, and Testing of Twin Incubator Based on the Concept of Grashof Incubator, *The 10th International Meeting of Advances in Thermofluids (IMAT 2018)*, AIP, DOI: https://doi.org/10.1063/1.5086560, 2062(1), 020013-1–020013-7, 2018.

[28] Rashid, F.L.; Basem, A.; Hussein, A.K.; Al-Obaidi, M.A.; Bechir, M. (2023). Advancements and Innovations in Thermodynamics for Infant Incubators: A Review, *International Journal of Heat and Technology*, DOI: 10.18280/ijht.410616, 41(6), 1543–1553, 2023.

[29] Sadhana, B.; et al. (2022). Child monitoring System using GPS Child Tracking System, *International Journal of Engineering Applied Sciences and Technology*, DOI: https://doi.org/10.33564/ijeast.2022.v07i01.051, 7(1), 329–337, 2022.

[30] Salahuddin, N.S.; et al. (2024). Aplikasi Sistem Pelacakan Inkubator Neonatus Jinjing Berbasis GPS Dan GSM, *Hak Cipta (PDKI)*, EC002024185572, 2024.

[31] Salahuddin, N.S.; Sari, S.P.; Musyaffa, A.R. (2024). Portable neonatus incubator based on global positioning system, *International Journal of Reconfigurable and Embedded Systems (IJRES)*, DOI: http://doi.org/10.11591/ijres.v13.i3.pp735-747, 13(3), 735–747, 2024.

[32] Sendra, S.; Romero-Díaz, P.; Navarro-Ortiz, J.; loret, J. (2018). Smartinfant incubator based on LoRa networks, In *2018 IEEE/ACS 15th International Conference on Computer Systems and Applications (AICCSA)*, DOI: 10.1109/AICCSA.2018.8612863, 1–6, 2024.

[33] Shaib, M.; Rashid, M.; Hamawy, L.; Arnout, M.; El Majzoub, I.; Zaylaa, A.J. (2024). Advanced Portable Preterm Baby Incubator, In *2017 Fourth International Conference on Advances in Biomedical Engineering (ICABME)*, DOI: 10.1109/ICABME.2017.8167522, 1–4, 2017.

[34] Shinde, A.; Patil, N.; Patil, S.; Gaikwad, P.; Vidya, N.A. (2019). IoT based baby incubator, *International Research Journal of Engineering and Technology (IRJET)*, 6(2), 914–915, 2019.

[35] Sukma, H.A.D.; Tiwari, S. (2021). Risk Factors for Premature birth in Indonesia, *Jurnal Biometrika dan Kependudukan*, DOI: https://doi.org/10.20473/jbk.v10i1.2021.61-67, 10(1), 61–67, 2021.

[36] Sunilkumar, M.H.; et al. (2023). Child safety and tracking system (CSATS), *World Journal of Advanced Research and Reviews*, DOI: https://doi.org/10.30574/wjarr.2023.18.1.0725, 18(1), 1048–1052, 2023.

[37] Taha, A.T.; et al. (2023). Child tracking system using smartphone, *Bulletin of Electrical Engineering and Informatics*, DOI: https://doi.org/10.11591/eei.v12i5.5161, 12(5), 2745–2752, 2023.

[38] Utomo, S.B.; Irawan, J.F.; Mujibtamala, A.; Nari, M.I.; Amalia, R. (2021). Automatic Baby Incubator System with Fuzzy-PID Controller, *IOP Conference Series: Materials Science and Engineering*, DOI: 10.1088/1757-899X/1034/1/012023, 1034(1), 012023, 2021.

[39] Wanda, D.B. (2018). Public Health Implications of Very Preterm Birth, *Clin Perinatol*, DOI: 10.1016/j.clp.2018.05.007, 45(3), 565–577, 2018.

[40] Widhiada, W.; Antara, I.N.G.; Budiarsa, I.N.; Karohika, I.M.G. (2019). The Robust PID Control System of Temperature Stability and Humidity on Infant Incubator Based on Arduino AT Mega 2560, *IOP Conference Series: Earth and Environmental Science*, DOI: 10.1088/1755-1315/248/1/012046, 248(1), 012046, 2019.

[41] Koo, K.Y.; Hester, D.; Kim, S. (2019). Time Synchronization for Wireless Sensors Using Low-Cost GPS Module and Arduino, *Frontiers in Built Environment*, DOI: 10.3389/fbuil.2018.00082, 4(82), 1–15, 2019.

[42] Zaelani, V.A.; Koestoer, R.A.; Roihan, I.; Harinaldi. (2019). Analysis of temperature stabilization in grashof incubator with environment variations based on indonesian national standard (SNI), *AIP Conference Proceedings*, DOI: 10.1063/1.5086550, 2062(1), 020003, 2019.

[43] Zhang, H.; Li, T.; Li, Z. (2009). Modeling in SolidWorks and analysis of temperature and thermal stress during construction of intake tower, *Water Science and Engineering*, DOI: 10.3882/j.issn.1674-2370.2009.01.009, 2(1), 95–102, 2009.



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