

Incubator for Home-based Baby Care Using IoT

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Abstract The incubators are the critical components of hospitals to save premature babies. In this paper, we have discussed the development of incubators till now. Furthermore, the applications of incubators and the conditions affecting new-born babies are also discussed in the paper. Integrating internet of things (IoT) technology with incubators is the main feature of our developed prototype. The information about the incubator ambient environment status goes to the doctor, nurse, or family member through the internet with the help of ThingSpeak, an open IoT platform for necessary action. The incubator environment controlling feature is also there, and it is implemented with a Peltier-based device that can cool and heat the incubator chamber. The proportional, integral and derivative (PID) algorithm was used to control the incubator chamber temperature. The developed prototype was tested in real-time using IoT. The developed prototype shows promising results in attaining the set temperature within 2 to 3 minutes. In addition, the device shows all the ambient sensor data, humidity and the Peltier status on the prototype and the user's smart mobile application. The developed incubator is affordable and suitable for countries and working parents in resource-poor settings. The developed system can also be used for point-of-care applications while sending the incubator's data in real-time to the parents-hospitals.

Keywords: incubator, toddler, IoT, ambient environment temperature control, humidity

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1. Introduction

The initial 28 days are very crucial in neonatal life. According to a report, 2.4 million infant deaths were reported globally in 2020 during the first month after birth [1]. And the few initial days are critical for them—the reason for this large number of deaths in the child's premature birth. The possible solution to overcome this problem comes after the use of incubators. These alternate arrangements provide a mother's womb-like environment for premature babies. Presently, much research is going on to develop intelligent and multi-featured incubators. The aim is to build incubators which are safe, secure, and have multiple features. The present work focuses on such an incubator with all the above-mentioned features.

The rest of the paper is organized in the following manner. Section II describes the literature survey of incubators, and section III focuses on developing IoT-based incubators, section IV discusses the incubator system procedure, and section V discusses the results. In section VI, the conclusion of the paper is discussed.

2. Literature Survey on Incubators

Premature babies require proper time to develop their organs. They may have breathing troubles, infections, the

effect of gestational diabetes, jaundice, the trauma of a long or stressful delivery, suffering from a surgical procedure, respiratory misery syndrome, hypoglycemia, or sepsis. The central system required for such babies is a controlled temperature and humidity environment with proper oxygen. The major problem with premature babies is that they cannot express their problems. One has to rely on the sensing and actuation-based systems inside the incubators. They provide the necessary vital statistics of the toddlers, such as heart rate.

According to the literature, a neonatal incubator is a place of enclosed equipment where premature babies can be kept in a controlled, safe, clean, caring and observation-based environment. The continuous real-time monitoring of the babies reduces the death rate and other complications. Rajalakshmi et al. concentrated on presenting incubator systems with prime biological parameters, analysis techniques and modes of transmission of the information. According to them, any baby born before 37 weeks comes under the category of a premature baby [2]. The present researchers are focusing on cardiorespiratory, temperature, blood pressure, transcutaneous oxygen, and carbon dioxide monitoring. They are using techniques based on ultrasound, X-ray, mechanical ventilation with IoT, and magnetic resonance imaging principles. The crucial parameters of incubators are infant's body temperature, weight, incubator temperature, humidity, sound cancelling, and gas density adjustment. Oyebola et al. suggested the control of

parameters such as temperature, humidity, and oxygen concentration inside the incubator. They measured temperature and humidity inside the incubator using LM356. According to them, the present cost of incubators is high and needs to be lowered [3]. In the mid-nineteenth century, the infant incubator was based on the incubators for chicken eggs developed by Dr Stephane Tarnier, also known as the incubator's father [4]. Alexandra Lion developed a more sophisticated incubator than that from Tarnier's work. It consists of a large metal apparatus having a thermostat and an independent forced ventilation system. This incubator was designed to compensate for the less-than-optimal nursing environment.

Otalora et al. implemented an intensive care incubator prototype with a fuzzy logic-based control system. It maintains the newborn's temperature through two operation ways: baby and air. Similarly, the chamber's humidity is controlled according to the patient's gestational age. ZigBee wireless communication protocol is used to communicate the incubator with the monitoring station. It has low power consumption, ease of integration, low data flow transmission and speed of up to 250 Kbps [5]. Huang et al. presented an intelligent infant incubator system based on IoT in detail. They illustrated that the system's overall architecture is based on the layer framework of IoT. They designed the intelligent local gateway based on Zigbee technology and a type of ARM1136J board. Their system software design is presented, marked by loading balancing technology, Hypertext Transfer Protocol and Extensible Markup Language [6]. Tisa et al. designed and developed an enhanced feature temperature control system. It incorporates a combination of Pulse Width Modulation (PWM) and a simple ON-OFF control system. They used thermistors as temperature sensors. According to them, premature infants are at risk of developing hypoxia, hypothermia and many other associated adverse conditions, so they need special care and attention. One of the significant problems that newborns face is improper thermoregulation [7]. Velagic et al. developed a system composed of the incubator, a programmable logic controller based PID controller, a human-machine interface, a direct current dimmer as an actuator and a negative temperature coefficient temperature sensor [8]. Jabbar et al. proposed an IoT-based Baby Monitoring System for real-time monitoring. They proposed a new algorithm that plays a crucial role in providing better baby care while parents are away. The Node Micro-Controller Unit (NodeMCU) Controller Board was used for the data transmission of the baby's vital parameters. The parameters monitored and communicated were the ambient temperature, crying and humidity. The developed prototype uses Nx Siemens software, and the material used to make the cradle was red meranti wood [9]. Chatterji et al. have also shown the online monitoring and the control of the temperature and humidity for the small closed chamber. [10]

Shin et al. created a wireless network to monitor the temperature and humidity of infant incubators. The system combines infrared and radio frequency communication to minimise the power consumption of secondary devices. So, it is a kind of hybrid wireless network [11]. Oliveira et al. presented a system based on a microcomputer that assesses infant incubators' performance in a semi-automatic

manner. The developed electronic circuit acquires the data from the sensors using a microcontroller. They have used sensors for temperature, humidity and airflow. The sampled data is sent to the computer via Bluetooth [12]. Fic et al. proposed modifications to the geometry and operation of the radiant warmer. It makes the temperature distribution more uniform and prevents the high-temperature gradients observed on the surface of the neonate [13]. Kumar et al. proposed an implementation of a real-time web-based system to monitor Infant temperature, humidity, weight and physical conditions. It controls infant's temperature, humidity, and other physical conditions. The neonate activities in the incubator and its parameters were monitored using camera and vision assistant software. It also takes the help of the Web Publishing tool of Laboratory Virtual Instrument Engineering Workbench-2011 software which monitors and controls incubator parameters from a remote location [14]. Shin et al. developed and installed an intensive care unit (ICU), a web-based real-time operating, management, and monitoring system to check temperature and humidity within infant incubators. A pilot system has been created with a temperature and humidity sensor and a measuring module in each incubator. It connects to a web-server board via an RS485 port. They have used Transmission Control Protocol /Internet Protocol to transmit signals so that the users can access the system from any internet terminal present in the hospital [15]. The baby's weight is one of the important parameters of interest, showing the health conditions. Widiyanto et al. developed a load cell-based real-time baby weight measuring system [4].

2.1. Development of Incubators

Regularly monitoring and controlling the premature baby's health parameters is challenging with the existing manual approach. A need arises to automate the process by continuous monitoring of these parameters. The incubators were developed to make it possible. The earlier incubators were either air mode management or skin temperature management. The warm air goes near the baby to prevent heat loss. Similarly, the humidity was a critical parameter monitored and controlled in an incubator. The monitoring and control systems become cost-efficient using microcontrollers such as the PIC family. Better integrated circuit modules were developed that can measure both temperature and humidity. The later incubators added one more feature to the incubators: the oxygen monitoring and control of premature babies. Then, with the developments in wireless sensor networks, their use in incubators improved their performance. Then, other parameters such as heart rate, respiration rate, and oral temperature were also monitored. The development of non-invasive approach-based sensing technologies also helped monitor electrocardiogram and peripheral capillary oxygen saturation (SpO2) parameters.

2.2. Conditions Affecting Infants

Different conditions affect the admitted babies in the neonatal ICU. There are interventricular haemorrhage, periventricular leukomalacia, nosocomial infection,

pneumothorax, and others. Almost 20% of preterm toddlers weighing 1500 gm tend to broaden an intraventricular haemorrhage (IVH). The haemorrhage takes place during the primary few days of life. The critical hazard elements for IVH are extreme immaturity, pneumothorax, start asphyxia, and sudden boom of arterial blood strain. Periventricular leukomalacia is related to brain injury in premature infants. The ventricles, which are small areas of brain tissue around fluid-filled areas, become dead under this condition.

In hospitals, patients with different diseases get admitted and may pass some infections to other patients. Toddlers are also susceptible to these infections. These kinds of infections are known as nosocomial infections. Premature babies also have a chance of pneumothorax. In this condition, air leaks into a region between the chest wall and the lungs, making the lungs collapse.

So many researchers have monitored different vital parameters, but they are not cost-effective. The earlier-developed incubators can only be used for hospitals. They use compressors to control the ambient environment and are costly and energy-consuming. Hence it cannot be employed in resource-poor settings countries. The trained staff can only operate the systems. But there is still the requirement to monitor the baby in the early days when the baby discharge from the hospital. At home, not everyone has controlled temperature environment and if they have, they set the temperature of the AC at about 25°C, which is also not suitable for the newborn baby. Moreover, the parents cannot watch their babies at work. So, to solve the problems mentioned above, we have

developed an affordable, easy-to-use incubator based on the Peltier effect.

3. IoT-based Developed Incubator

IoT is one of the latest technologies finding its application in different areas. It describes the physical objects interfaced with sensors connecting and sharing the information with other devices or systems through the internet. For example, we added the IoT feature in the developed prototype infant incubator system. For sensing purposes, separate sensors for temperature and humidity are used. The sensing information goes to the processing unit. The processed information gets published on ThingSpeak, an IoT analytics platform.

3.1. Block Diagram of the Incubator

The block diagram of the developed incubator is shown in Figure 1. The PIC 16F877A is used as a centralised controller for the incubator system. It consists of necessary ports, analogue to digital converters, and other peripheral units. The temperature and humidity information goes to the microcontroller through sensors. The regulated power supply provides the necessary power to different functional blocks. The driver, relay and Peltier crystal assembly are used to control the temperature inside the incubator. A liquid crystal display (LCD) is used to display real-time information. Finally, the microcontroller is connected to the IoT module to publish the information through the internet with ThingSpeak.

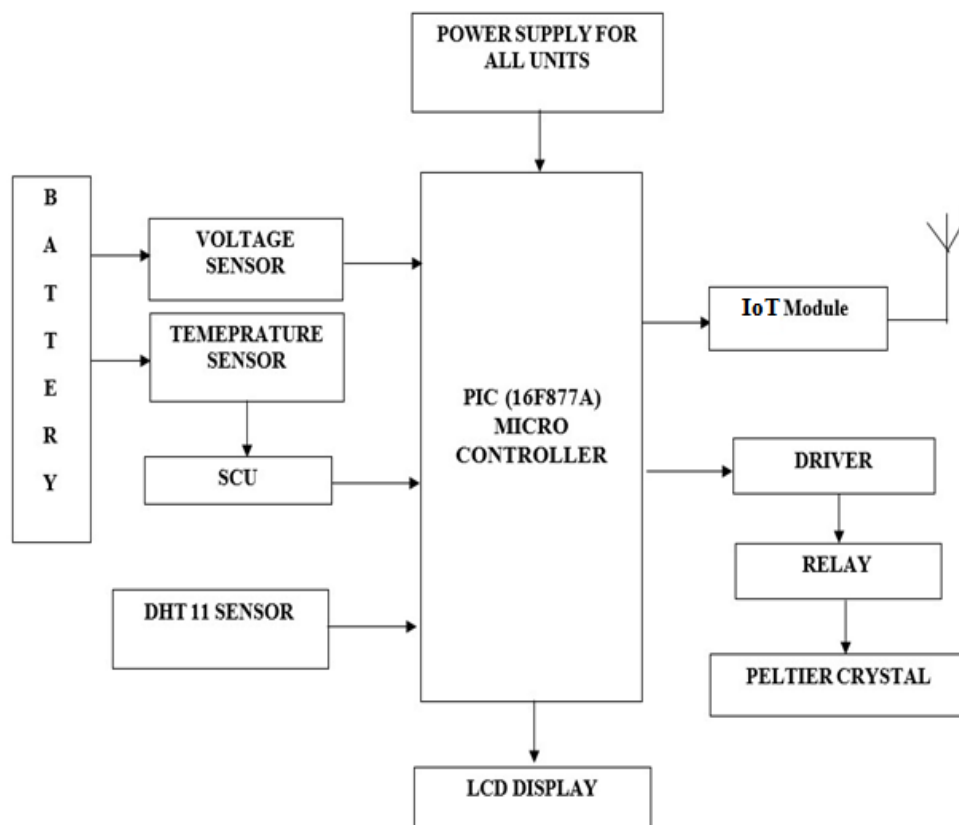


Figure 1. Block Diagram of the IoT-based incubator

3.2. Hardware Details

The PIC 16F877A microcontroller is a central controller for the incubator system. A total of two DS18B20-based temperature sensors are used to measure the temperature, and the DHT 11 sensor is used for humidity measurement of the incubator. NodeMCU ESP-8266 is used as an IoT module. It is programmed with the Arduino integrated development environment platform. The temperature and humidity-related information of the incubator gets published through the internet with ThingSpeak, a free IoT platform application on the Android-based smart mobile. The Peltier crystal

was triggered to maintain humidity and temperature in the incubator to warm the baby and controlled with the help of the driver and relay circuit. The PIC16F877A generates the PWM to the relay driver chip ULN2003. The driver then controls the Peltier relay. The heat sink attached to the Peltier gets heated whenever the Peltier is on. All the sensor data and the Peltier conditions are shown on the LCD. The IoT module was used to transmit the battery temperature & voltage level, incubator humidity and temperature to the smart mobile application. The developed hardware for the incubator is shown in Figure 2. (a). Figure 2. (b) shows the developed incubator using thermocol and the Peltier installed on it with the heat sink.

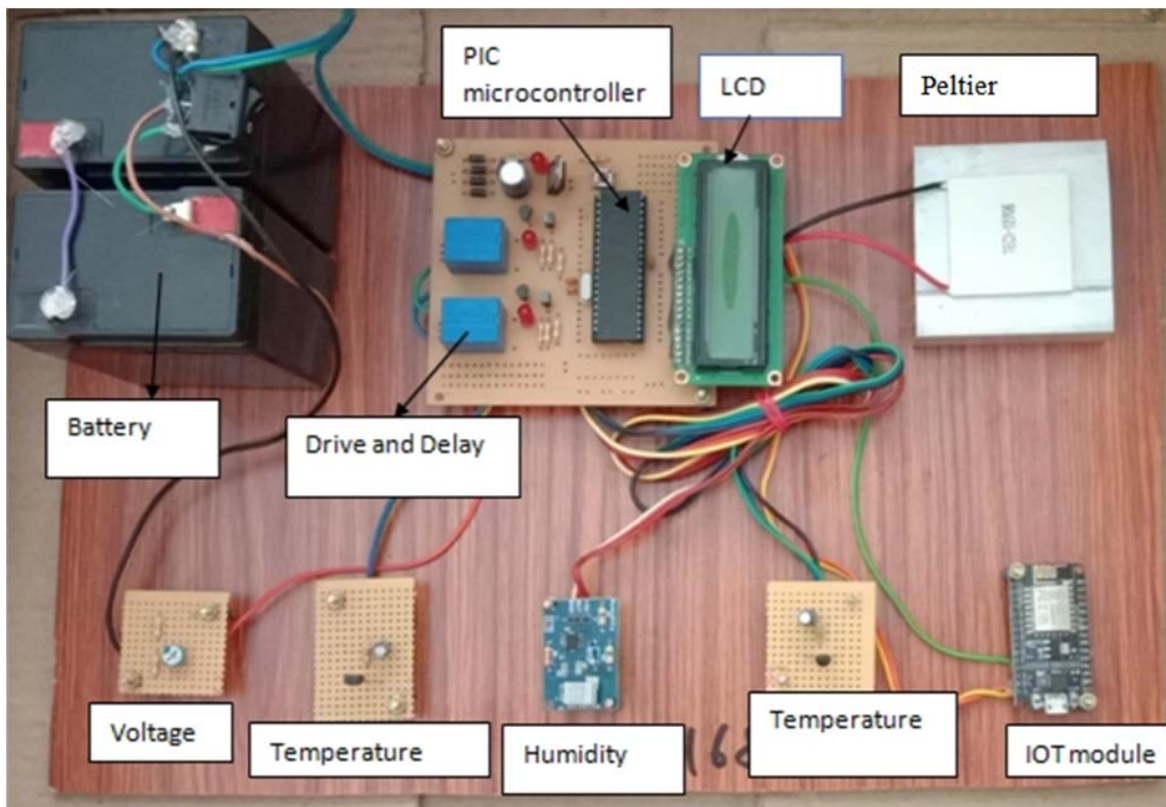


Figure 2. (a) Developed prototype for IoT-based incubator

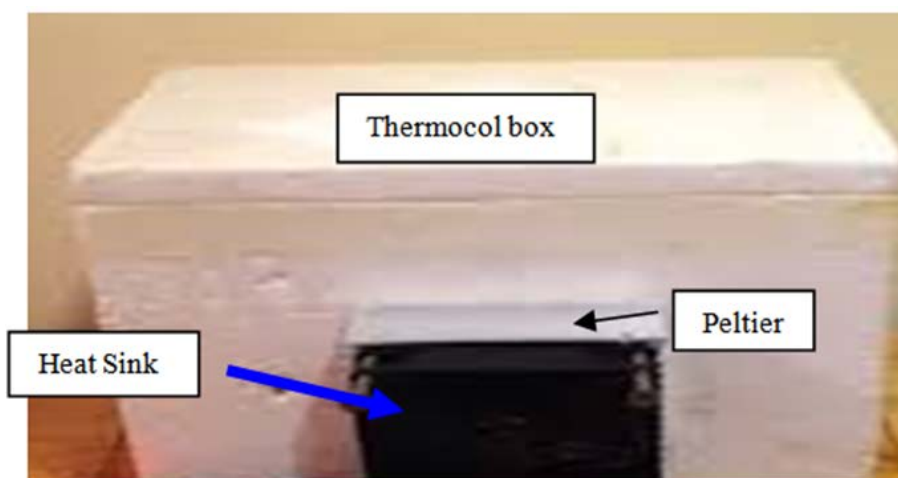


Figure 2. (b) Developed Incubator chamber using the thermocol-based box with the Peltier and heatsink installed

3.3. IoT Feature

In the current scenario, IoT is one of the fastest-growing technologies. Integration of the infant incubator monitoring system with IoT enables us to view the data obtained from the baby environment anywhere in the world with the help of our Smart Mobile, or it can be saved in Cloud and retrieved anytime for analysis. This feature is enabled by using an ESP-8266 nodeMCU module, which collects the data from the controller and updates it on the Cloud server via any available bearer services. The IoT module can be checked by sending the Message Queuing Telemetry Transport protocol. The microcontroller sends the sensor data to the IoT module every 5 seconds. The IoT module then sends this data to the smart mobile application once the connection with the user is established in real-time. We have to provide the username, client user name, and password of the website, which we need to post while configuring the ESP-8266 module.

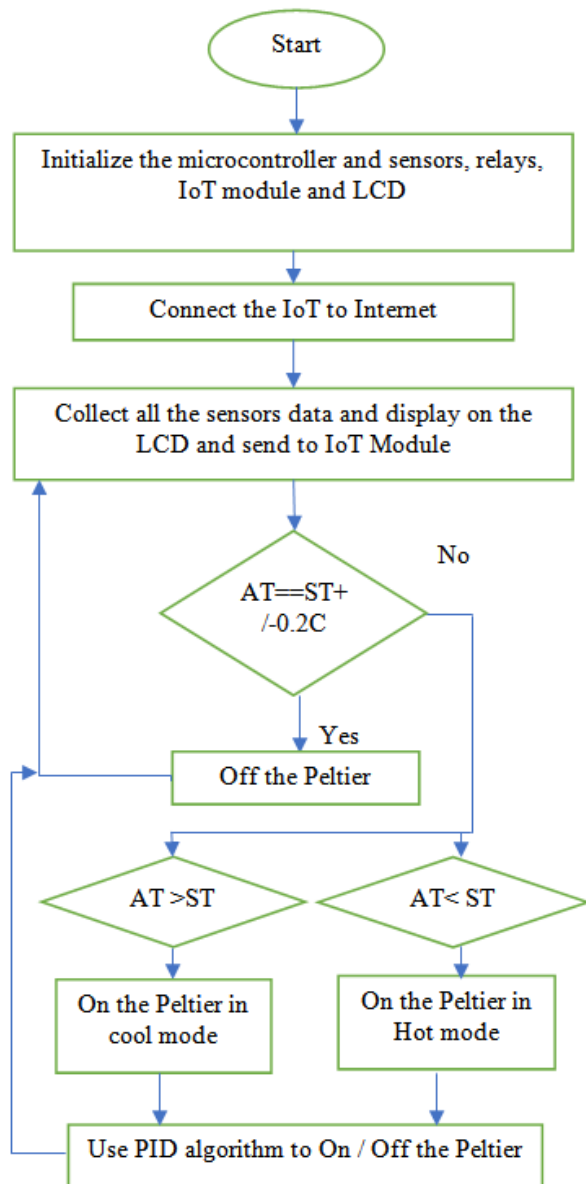


Figure 3. Software Flowchart for the Hardware Incubator

3.4. Software Flow of the Developed System

The software for the incubator hardware is written in C language using Arduino. The block diagram of the flowchart is shown in Figure 3. The software initialises the microcontroller, sensors, relays, LCD and IoT module. Then it connects the IoT module to the internet. After that, all the sensor data are collected and displayed on the LCD. Then the microcontroller checked the ambient temperature within the band of $\pm 0.2^\circ\text{C}$, and the Peltier was made off. If the set temperature (ST) < Ambient Temperature (AT), then the Peltier was on in the cool mode. If ST > AT, then the Peltier was on in the hot mode. It uses the PID algorithm to reach the set point to be maintained as per the incubator requirement. To heat or cool the Peltier, we reverse the polarity of the Peltier by using the H-bridge circuit. Then the Peltier starts to cool/heat the incubator chamber. After this, the whole loop repeats till the set point is attained by the system.

The flowchart for the smart mobile application is shown in Figure 4. First, the user has to open the smart mobile app. Then the user enters the user's name and password. Next, the app opened and checked for an internet connection if both were correct. If the internet connection is there, it checks for the IoT module. Once the relationship with the IoT module is made, it shows all the sensor data on the user's smart mobile. The patient data is uploaded to the free Cloud and is updated every five seconds for real-time display. The option to change the set temperature with a smart mobile application is also possible. It also alerts the doctors, nurses, or caretakers of the neonates inside the incubator via the IoT module to take necessary and possible actions to maintain the health of the preterm infants within the incubator.

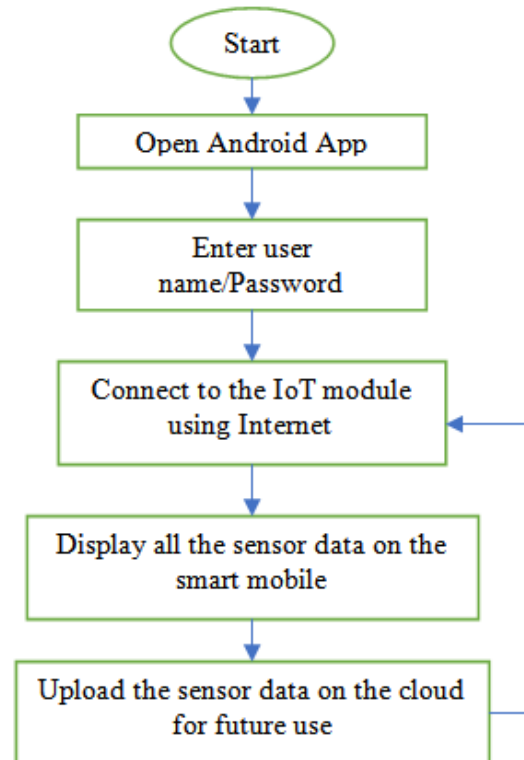


Figure 4. Software Flowchart for the Smart Mobile application

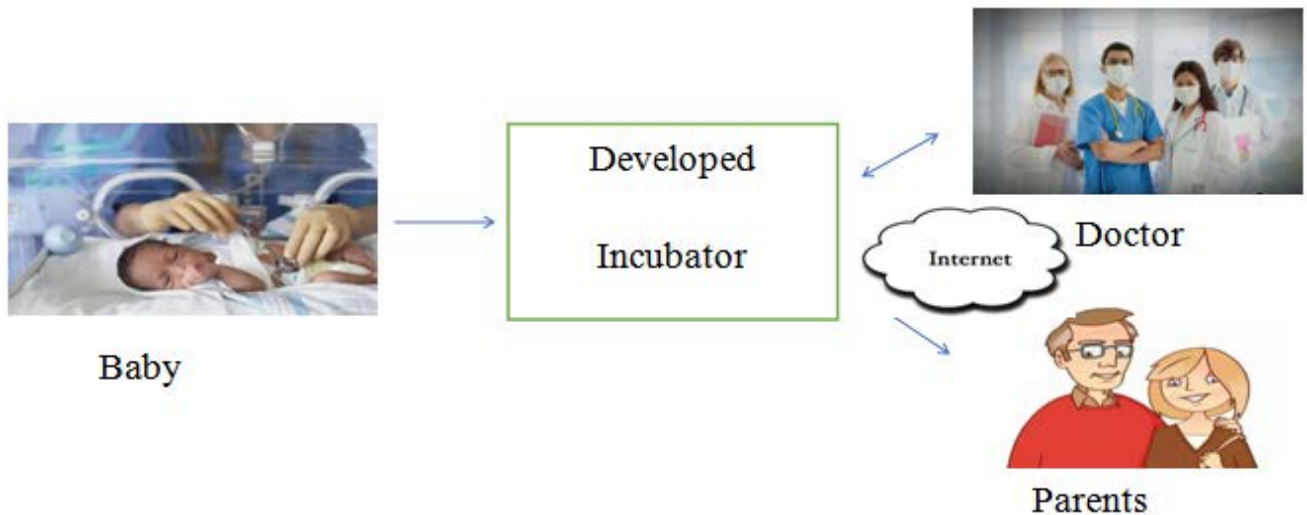


Figure 5. The procedure to use the developed IoT-based incubator system

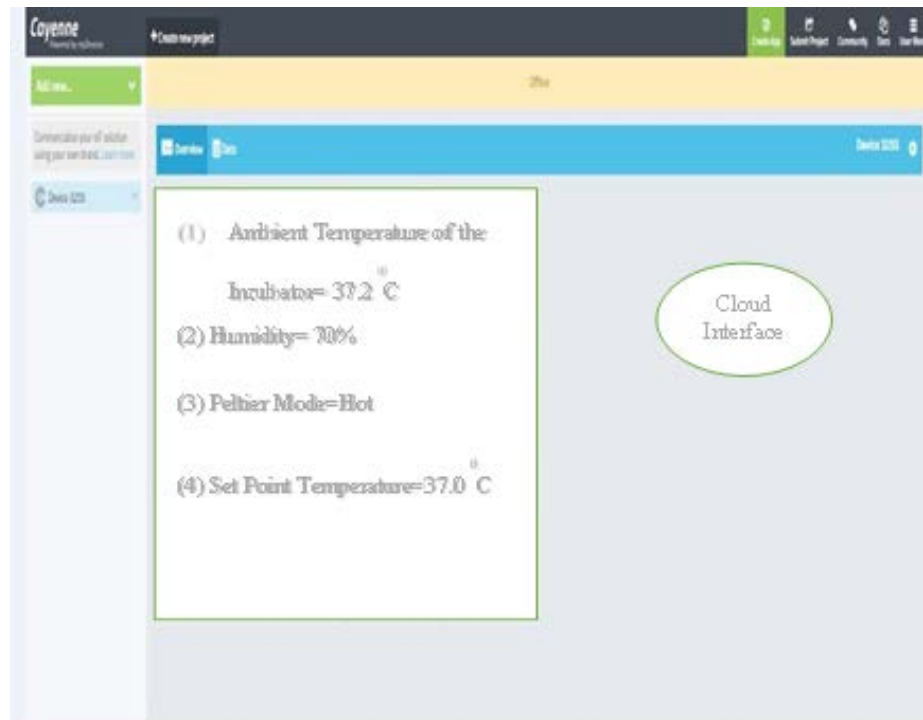


Figure 6. Displaying infant incubator parameters on web pages through IoT

4. Procedure of the Incubator System

The existing incubator systems are very complex to operate and are controlled centrally. However, the developed prototype can be used by any untrained professional. The block diagram for the procedure to use the developed incubator prototype is shown in Figure 5. The system reads the set temperature and compares it with the ambient temperature. The user can put the baby in the incubation chamber once the temperature is achieved. After this, the baby can be monitored with the help of a smart mobile application. The smart mobile user can monitor the incubator chamber's status on their application. The snapshot of the smart mobile application showing the incubator parameter is shown in Figure 6. The application shows different temperature sensors attached to the incubator unit, humidity values, and Peltier status. The

app also provides a button for the Cloud for interfacing and uploading the coming data.

5. Results

The procedure for baby monitoring is simplified and tested in real-time using IoT. The developed incubator was tested on the thermocol-based box procured from the local market, and the Peltier and the heat sink were installed and controlled with the developed IoT-based system. The box also contains temperature and humidity sensors to monitor and control the ambient parameters as required. The box size was chosen to simulate the incubator volume for a single child. The system can be used at home, even by untrained medical professionals. All the ambient parameters measured, for example,

ambient temperature and humidity, are displayed on the LCD and the smart mobile application. The prototype was tested in real time, and the response time of attaining the set temperature was found to be within 2 to 3 minutes. The PID algorithm tested on the control of the Peltier shows promising results. The component cost of the developed system is around 100\$. Hence it is very cost-effective for developing and resource-poor setting countries. The smart mobile application was a free platform for IoT-based systems and therefore free for the user. The developed system also has got less weight and size than traditional incubators.

6. Conclusions

The incubators are the key components for saving the lives of premature babies. The present work discusses all the details and literature survey of incubators. A discussion is there about the developments in incubators and conditions affecting premature babies. The prototype developed gives good real-time results online. Integration of the IoT with the Incubator provided more features to our system. We only monitored the ambient temperature and the humidity of the local environment of the baby to reduce power consumption and to make the system cost-effective. As the developed system is easy to use, we have interfaced the IoT to the developed app, and the caregiver-hospital can monitor the baby's ambient parameters online from anywhere. The developed system procedure is also simplified and can be used by non-trained professionals. The developed system is especially beneficial to parents working alone who wants their baby to be taken care of automatically. The developed system cost is around 100 \$ which is very cost-effective for resource-poor setting countries. In future, more features and parameters can be included in the present system.

Some of these are body movement monitoring, heart rate measurements, weight, SpO2 and many more for the toddler. The system can also be miniaturised for the commercialization of the prototype. Hence the baby can be monitored automatically every time and serves the true purpose of the healthcare device that can be used as a point-of-care setting.

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Ethical Approval

The study does not require any ethical clearance because we had not done any medical trials and tested the instrument without the human component.

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