A Low-cost IoT based Infant Incubator: A Case of Mount Meru Referral Hospital in Tanzania

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Abstract

Physical adjustment to life for a premature baby outside of the mother's body is challenging due to health issues and other environmental factors. Prematurity is one of the most crucial problems in Tanzania since it contributes to a greater infant mortality rate. Despite the vital function that infant incubators play, the majority are too expensive for low-income countries to obtain and rely only on mains electricity. The fundamental goal of this project is to create an inexpensive, efficient, and dual-powered incubator that saves premature infants' lives. We are developing the system utilizing ESP32 as the MCU interfaced with DHT22, a thermistor for skin temperature, MAX30102 to evaluate heart rate and oxygen saturation in the blood. An oxygen sensor measures the air quality in the chamber, and a UV sensor records the light intensity of the phototherapy unit used to treat jaundice. The computed information is displayed and transferred to a webpage that tracks the infant's data. When the system detects a critical condition, it sounds an alarm and sends an SMS to medical personnel via GSM. The system adjusts the environment using a heater, humidifier, and oxygen valve included. The final design was implemented on a PCB and tested after a circuit was designed and simulated. The sensors are calibrated against standard sensors to receive accurate measured data, as then transferred via Wi-Fi through the ESP32 to a webpage for remote monitoring and control. The system saves the lives of premature babies, is low-cost, and is applicable in areas with limited resources.

Keywords:

ESP32, Web server, low cost, multi powered, premature incubator

1. Introduction

A child's birth is both a delightful and painful occasion since it can be difficult to acclimatize to life outside of the mother's body, both physically and emotionally for a newborn due to number of health reasons. Yearly, an estimate of four million children dies globally, with the vast majority of these deaths occurring in developing countries, whereby it has been noted that the first seven days of life account for half of all deaths [1].Additionally, it has been noted that the worldwide preterm delivery problems which accounts for 35%, are the leading cause of neonatal deaths, followed by birth asphyxia at 24%, and infections which include sepsis, pneumonia, and meningitis is at 20% [2, 3]. In Tanzania, where this study has been conducted, the birth asphyxia which accounts for 31% is the furthermost cause of neonatal fatalities, followed by preterm birth problems at 25%, and infections such as sepsis and meningitis at 20%, and pneumonia at 5% [4]. Based on the statistics, it can be vividly observed that there are complications associated with premature birth both to the mother and the baby and nearly 5 to 18 percent of pregnancies which are preterm birth are regarded as the source of morbidity and mortality in infants [5]. By definition, premature birth is a baby born in less than thirty-seven (37) weeks or less with a weight under 5.5 pounds. Therefore, due to health condition complications necessitate close attention [6] and hence, the premature newborns are cared for at the neonatal intensive care unit (NICU) in order to prevent complications during delivery, or develop difficulties while still in the hospital [7]. Therefore in the NICU, the premature babies are placed in the incubators which provide a regulated and protected environment for their care [8].

Due to these challenges, the advancement in science and technology has been applied to strengthen various operating tools which are used in the NICU including the incubators. Hence, as a result of applying science and technology in the area, neonatal care has improved, resulting in increased survival rate. For example, in 2006, the number of children dying before reaching their fifth birthday decreased to 9.7 million from 10 million in the previous year worldwide [9]. Additionally, in the year 2015, the neonatal mortality rate was 21 per 1,000 live births in

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Tanzania [10]. However, due to existing measures done by several researchers, medical experts and scientists in the area of premature birth, there are still existing operational challenges in most of the devices since the operation cost is high and they depend on electricity which is unreliable in most of the African countries. Therefore, in order to overcome the operational cost in the existing incubator, this study intents to describe in details the design and development of a low-cost multi-powered IoT-based infant incubator which can be easily operated by the NICU's to provide premature babies with the necessary healthy environment for their growth hence increasing the survival rate.

2. Related works

This section presents briefly the overview of existing studies which were done to improve the operational and technical functionalities of the incubators. There are several studies [11] [12] [13] [14] that involved monitoring and control system of infant incubator in which mainly temperature and humidity were controlled .Other studies [15] [16] [17] [18] [19] [20] done using IoT to monitor the healthcare of the babies and then send the data to the cloud and later the information is sent to the medical personnel in charge. Unfortunately, these measures have been having shortcomings such as lack of real time in sending the notification and also, they depend highly on internet and electricity for their operation.

The other studies have used wireless technologies [21] through the use of a LoRa-based Smart Infant Incubator. The devised system is linked to a central network through LoRa, allowing medical data to be stored in a database. Through the use of the system, clinicians may be identified and be able to check the patient's status and progress via a smart device, as well as add new data through Near Field Communication (NFC). In India, a large number of academics have taken a variety of approaches to the problem by designing an IoT-based bay incubator healthcare system [22] through the integration of IoTCC3200, a temperature sensor, a heartbeat sensor, a cry sensor, and a humidity sensor coupled into an MSP430 microprocessor. In addition, the measured variables in this system are also sent to the cloud for analysis causing a similar challenge of electricity dependence in its operation and lack of real time information for decision making.

Additionally, the other existing studies have focused on heat control is one of the fundamental aspects of premature health growth [23]. The system monitors the parameters using infrared sensors and gel packs to maintain the appropriate temperature for the newborns. The other similar study was done Africa specifically in Nigeria [24] and Sudan [25] which created a low-cost IoT-based neonatal incubator for resource-poor African environments. However, these systems depend only on electricity to operate though [26] developed a solar-powered infant incubator although cost wasn't addressed in this case . Hence, there are still operational challenges which needs different and multi-dimensional interventions which will be describe in this paper.

3. Material and methods

3.1 Case Study

The study area for this study is Tanzania where by four hospitals were involved. These hospitals including Mount Meru hospital in Arusha, Bugando hospital in Mwanza, AICC hospital in Arusha, and Muhimbili hospital in Dar es Salaam as shown in Table 1. These hospitals were selected due to the fact that they are some of the referral, national, and normal hospitals with NICU for storing premature babies.

Table 1: Four Hospitals which were used in this study

SN	Hospital Name	Region	Type
1	Mount Meru Hospital, Arusha	Arusha	Referral
2	Bugando Hospital, Mwanza	Mwanza	Referral
3	Muhimbili Hospital, Dar es Salaam	Dar es salaam	National
4	AICC	Arusha	Normal

3.2 Hardware and Software Requirements

3.2.1 Description of the Software Tools Applied for the Development of Incubator Unit and Website

The following are software tools which were used to develop the incubator; proteus was used for circuit design, simulation, and PCB design, whereas Arduino IDE was used for ESP32 programming in the C language. Whereas, for the website development, the following software tools were used which include CSS, HTML, and JavaScript which were used for front-end programming, while PHP and JavaScript were used for back-end programming. Additionally, XAMPP server with MySQL was used as a database in web server for local hosting of the website.

3.2.2 Description of the Integrated Hardware Components

Table 2 describes the list of hardware components used in the development of the system

Table 2: Hardware parts used

Component	Description
ESP 32	A powerful generic board with the ESP32-D0WDQ6 dual-core microcontroller chip, clocked at 80 and 240 MHz The board has built-in Wi-Fi, Bluetooth, and several peripherals such as SPI, UART, I2C, I2S, and others, making it suitable for a wide range of applications. Additionally, the board Arduino IDE compatible, making its programming and usability functionalities easy to implement
Metal Head Thermistor	A stainless steel-covered waterproof 10 KΩ negative temperature coefficient resistor that measures temperatures from -20 to 105 °C with a precision of -/+ 1% of the observed temperature.
DHT22	A temperature and humidity sensor used to measure its adjacent environment. The thermistor for temperature and a capacitive transducer for humidity is connected with an 8-bit single-chip computer and outputs a digital signal that is single-bus data interface communication with the MCU.
MAX30102	Measures heart rate and SPO2 sensor based on LED reflective gadget. The gadget is connected through I2C to the MCU
Air Quality Sensor	a gas sensor used to measure air quality in parts per million (PPM).The sensor is 5V powered as its air quality measurements is computed using the MCU's ADC
UV/GY 6070	Sophisticated sensor with spectral sensitivity to cover the UV spectrum. The sensing part is used for UV light sensors that operate from 2.7V to 5V. The sensor uses an I2C communication interface with the MCU
Heater	Turns electrical energy into heat energy which is used to warm its surroundings. The heater keeps the temperature at the desired level by radiating heat via the airflow
Fan	12V fan that spins at around 3200 RPM, then, draws fresh air in from the outside, and later, circulates it inside the device. Hence, it is used to cool the devices when the temperature rises above the specified point
Humidifier	Ultrasonic humidifier figure 3(c) is a metal diaphragm vibrating at a high frequency of about 113 kHz to produce a warm or cool mist. Moisture is propelled into the air by acoustic pressure.
Solenoid Valve	An electrical actuator that opens when 12 Volts (V) of voltage is provided to its terminals, allowing one-way passage of the existing oxygen gas
GSM Modem	SIM800L a four-band GSM/GPRS module has GSM850MHz, DCS1800MHz, PCS1900MHz, and EGSM900MHz as working frequencies. It uses the UART communication protocol to connect the device to the MCU.

3.3 System Architecture and Description

The system consists of several input devices (sensors) and output devices, all of which are connected to an ESP32, as shown in Figure 1. Individual sensor measures and transmits the associated parameter to the MCU, which is then processed and when any measured parameter deviates from the predetermined value, the MCU activates the relays to regulate the condition to normal. Therefore, any sensed critical condition triggers an alert, which sends a text message to medical personnel. Through the web application, the equipment as a whole can be controlled and monitored from afar.

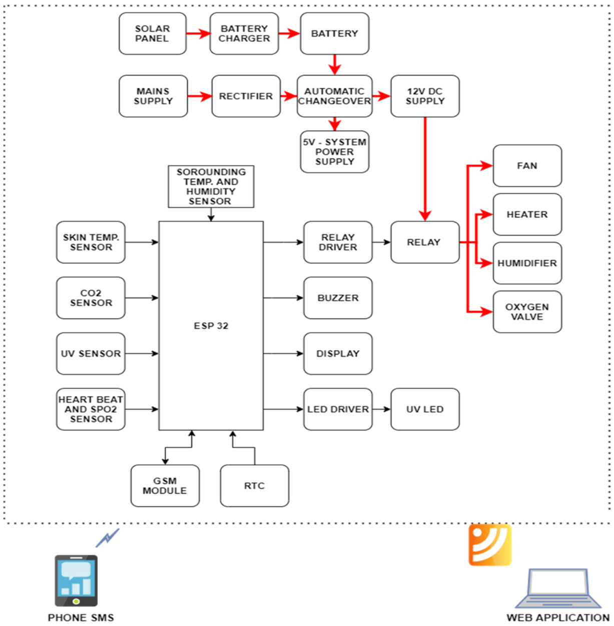

Figure 1: Developed System Block Diagram

The developed incubator has the following tools which are integrated to enable its effectiveness use at a low-cost. These tools include the sensing, processing, display and alerting, control units, and web server were designed as part of the created system. The sensing unit consists of DHT 22, thermistor, MAX30102, and UV/GY 6070, which are responsible for the infant parameter computation. This part is responsible for the temperature and humidity of the environment, temperature of the baby's skin, heart rate, blood saturation, and UV light intensity measurement. It is a crucial component of the system since it communicates the infant's status to the controller for monitoring. The MAX30102 and UV/GY 6070 utilize the I2C interface, DHT22 utilizes a single bus data interface, and thermistor uses an ADC interface to the microcontroller unit. The other part consists of a processing unit which is an ESP32-WROOM powerful board that includes the ESP32-D0WDQ6 microcontroller chip, which has two CPUs running at 80-240 MHz and 3.3V.

Its board is connected to the sensors as indicated in Figure 5, receiving, processing, and analyzing sensor values and control this is because the board is Wi-Fi enabled. Hence, data can be sent to the cloud over the internet, allowing for remote monitoring and control. The other part is the Actuator Unit which consists of an oxygen valve, fan, heater, and humidifier connected to the MCU via relays and controlled. Through the use if control unit the measured parameter from the sensors such as air quality, chilling and circulating the air, warming the surrounding, and treating jaundice can be easily regulated. Additionally, the other important part of the developed system is a display and alert unit which shows the measured parameter as well as the incubator status. In this situation, a TFT display was used, which is a wide-screen color matrix display. In addition, it has a buzzer which produces a buzzing sound with a frequency of around 2300Hz when a newborn is in severe condition and then, an SMS message is sent to the medical personnel for further action. The last part of the developed system is the web application through which the measured data and the incubator's operational state are sent to a web server through ESP32 over Wi-Fi. The operator can control and access the web database over the internet and deliver analytical conclusions based on the data collected. This website can also serve as a central repository for all neonatal data, both current and prospective.

4. Results and Discussion

4.1 Results of the System

The following are the outcomes of implementing the previously described system. Figure 2 illustrates the overview of the front and back end of the PCB design.

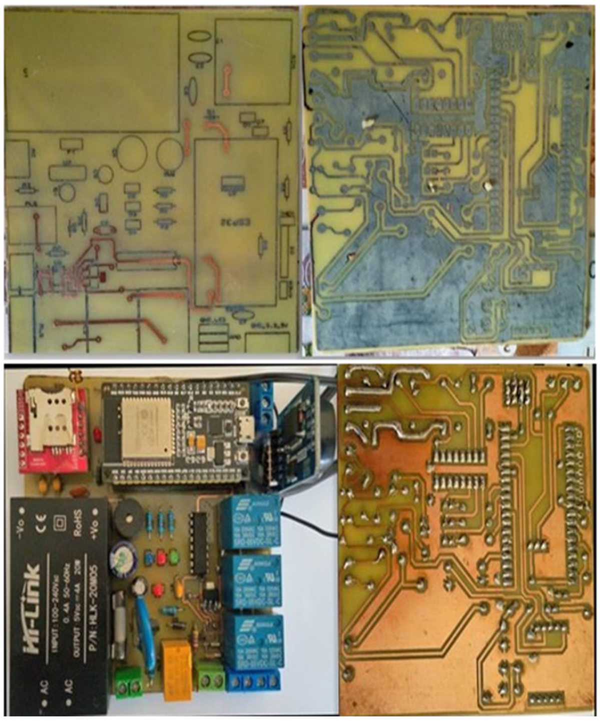

Figure 2: Front and Back End Overview of the PCB

In addition, the administrators can register a new user in the system or delete them as shown in Figure 3(a). Users are obligated to provide personal details such as full name, telephone number, and name of the department to mention a few. Additionally, the system can provide a username and a default password of the newly created user. Furthermore, the infant's particulars are registered to the system as shown in Figure 3(b). Moreover, the login page, user registration form, and the newborn registration form are all included in the built web server, as shown in Figure 3. The system also, rejects all other users and only accepts registered users who provide proper credentials. Also, users can be created, updated, and deleted by the administrator. Once the premature baby is admitted, the details including the name of the parents and the baby's weight, must be put into the database, as illustrated in Figure 3.

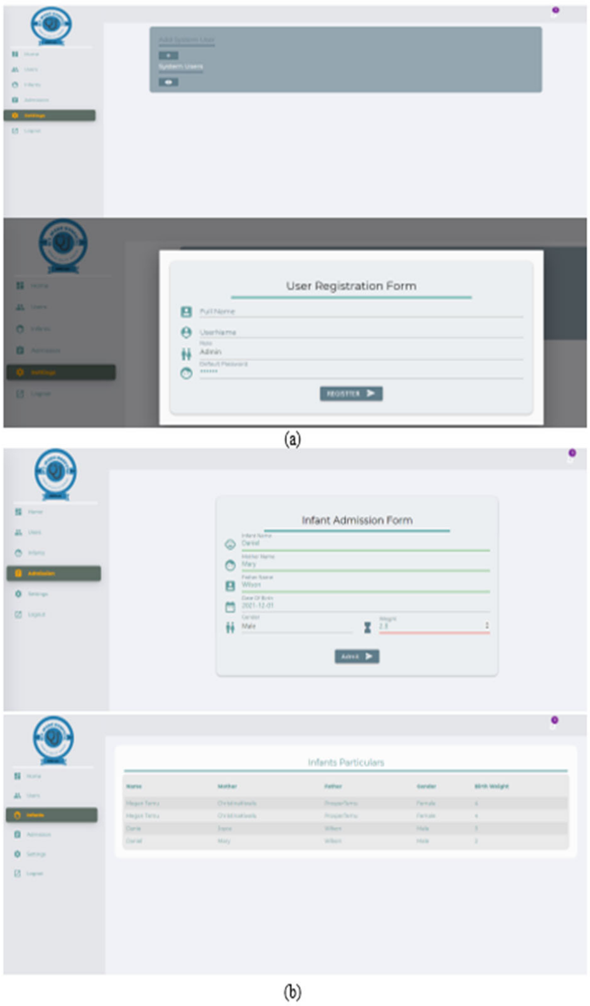

Figure 3: Interface for Registration Forms

4.2 System Testing

The testing phase of the prototype involved many samples from different people. The following data in Table 3 shows the average data recorded from the selected samples.

Table 3: Description of the Observed Test

Trial	Gender	Age	Heart Rate (Bpm)	SpO2 (%)	Skin Temp. (° C)	Air Temp. (° C)	Humidity (%)	Air Quality (%)
1	M	5-10	78	96	36.7	28.1	78	92
2	M	10-15	80	94	36.4	28.5	76	92
3	F	25-30	76	98	37.1	29.2	80	92
4	-	-	0	0	30.6	46.5	40	93

The final prototype which comprises of a well-designed housing with a transparent glass baby chamber, a height-adjustable unit, and drawers to keep diapers, medicine, and other related necessities as shown in Figure 4.

Figure 4: Prototype housing and tests results

The test involved several tests shown in Table 3 showing the results from the four tests. The data were presented on a widescreen monitor, as shown in Figure 4, and updated to the website every five seconds. Figure 5 also represents the visualization of the specimen involved and the data of temperature, humidity, heart rate, and blood oxygen saturation were sent to the webserver. Additionally, the texts message is sent to medical personnel when the infant is at the critical state as illustrated in Figure 6.

Figure 5: Description of the Graph Plotting

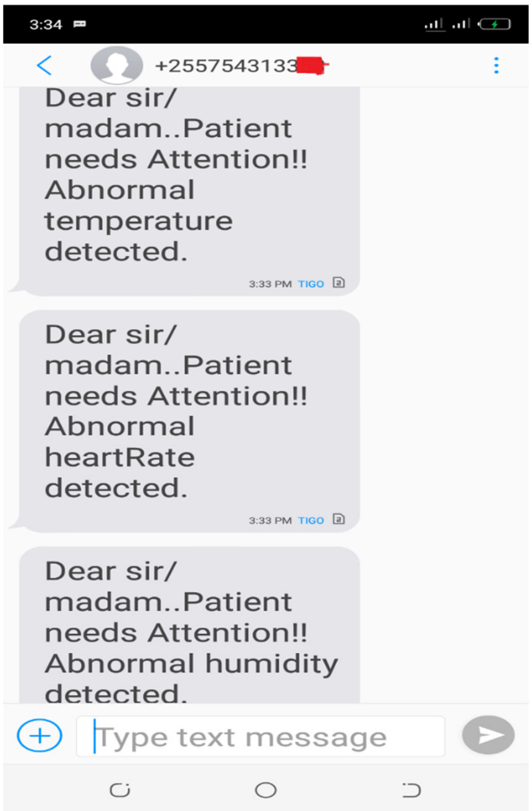

Figure 6: Interface Showing the SMS Notification

The other interface of the system is the temperature regulator which is a crucial component in any incubator. The temperature versus time were recorded to note the regulation pattern. Then, the baby chamber's size and the heater wattage determine the time for the system to stabilize the temperature from its initial condition of about 28-30ºC to the set one. The heater is turned on when the measured temperature falls below the predetermined value, depending on the mode of operation as shown in Figure 7.

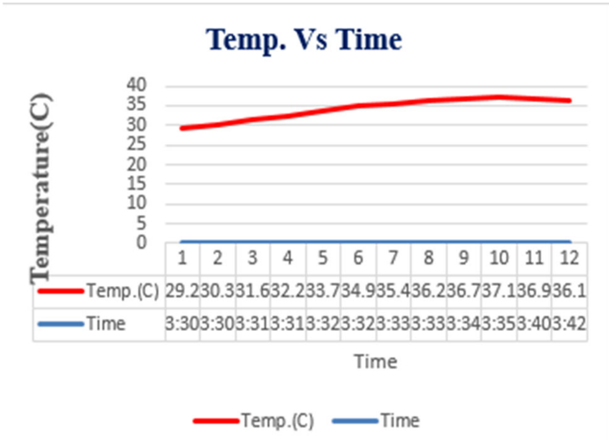

Figure 7: Graph Showing Temperature Regulation Characteristics

5. Discussion

Based on the existing challenge that most of the incubators are expensive and their operational cost is high, therefore this study has developed an incubator which can be purchased at 450 - 600 USD compared to the existing incubators which cost around 3,000 USD. Therefore, through the use of the developed system, the premature babies will be monitored and regulated utilizing technology that tracks and manages critical biological parameters to preserve their lives. The system has a sensor device to read environmental and biological data in the system using temperature and humidity sensor (DHT22), heart rate, and blood oxygen saturation using MAX30101. The MQ135 sensor measures the air quality and all interfaced to ESP32. Through the use of the heater, fan, humidifier, and oxygen valve equipped in the design, the MCU analyzes the sensor's computed data and adjusts the scenario to match the premature infant's healthy state. Additionally, the system has a phototherapy device which is in charge of treating jaundice, and a UV sensor which measures the light intensity. Hence, the system can send a text message and sounds an alarm to alert medical personnel when the infant is terminally ill. Furthermore, for easy tracking and control, the ESP32 sends all of the data to a webpage in which the medical personnel will have access to monitor the infant at a remote distance.

From results of the analysis, the humidity ranges from 40% to 60%, and temperature chamber adjustment takes around 4 minutes to attain the ideal temperature from a starting temperature of 24°C. As it is known that the power outage is common in most parts of the regions in Africa, therefore, is designed in such a way it can be powered by both mains and alternate sources such as solar. Hence, it can send real time data to the web page and notify medical personnel. Additionally, the system is integrated with phototherapy which assist in treating jaundice among premature babies. Lastly, based on the features integrated, the developed system can well assist the management of premature at low cost and hence, the newborn mortality rate can be easily reduced in underdeveloped countries through the use of this tool.

6. Conclusions

The designed system as shown in Figure 7,saves the lives of premature infants and is low-cost, multi-powered through the use of mains (220V AC and 12V) and alternative source such as solar, efficient, simple to use, and applicable in areas with limited resources. Furthermore, remote data monitoring and control via the web server guarantees its reliability. However, the study has the following limitations which include use of internet accessibility though there is an alternative of sending SMSs that alerts the medical personnel and also, lack of height adjustment. Therefore, the study recommends future studies to look into the issues of enabling sending information without the need of internet or SMSs and also, to integrate the height adjustment in the tool.

Figure 7: The designed prototype final view

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