ASHESI UNIVERSITY

A CHEAP AND PORTABLE WIRELESS INCUBATOR FOR PREMATURE BABIES

CAPSTONE PROJECT

B.Sc. Electrical & Electronic Engineering

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2020

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CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical & Electronic Engineering.

Khadijahtu Mohammed

2020

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

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Candidate's Name:

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Date:

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I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University College.

Supervisor's Signature:

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Supervisor's Name:

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Date:

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Abstract

The leading cause of child mortality globally is prematurity. These deaths mostly occur due to unavailable or high cost of keeping babies in clinical incubators, which provide controlled environment for premature neonates. The aim of this project is to develop a cheap and portable wireless incubator for premature babies. The project focuses on reducing the causes of preterm death and, as such, incorporates measures to minimize such factors. Hence, the incubator's other functions are to reduce Sudden Infant Death Syndrome (SIDS) and malaria. It has sensors to monitor vital environmental conditions of the incubator. It sends this information to the pediatrician to keep track of conditions that might affect the health of the baby. In order to maintain the set temperature continuously, the incubator can be powered from the grid and a battery used as an alternative. When in use, the battery is monitored with a battery level indicator. The incubator can maintain a constant temperature of 37°C and when the power supply is removed, it maintains that temperature for a minute and then gradually drops in temperature. A basket is used as the incubator's bassinette. The electronic components are cased and attached to the outside of the basket which makes the incubator portable. Buckwheat hulls was used for the mattress to help reduce SIDS caused by soft bedding which can lead to suffocation. The baby will be kept in the basket with the required dimension to reduce SIDS by avoiding instances of the baby rolling and having a face-down sleep as well as prevent bed sharing. A treated mosquito net is employed to reduce malaria.

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CHAPTER 1: GENERAL INTRODUCTION

1.1 The Problem

The World Health Organization in 2015 estimated that 1 million among 15 million of premature babies do not survive, hence ranking preterm birth the first fatal syndrome in the first month after birth and the second leading cause of death for children who did not complete their fifth year. Globally, the leading cause of child mortality is prematurity [1]. Half of babies born two months early or less die in low-income settings due to lack of feasible, low-cost care such as warmth, breastfeeding support, and basic care for infections [1]. In India, neonatal mortality accounts for nearly 50% of infant mortality [2]. Also, about 18% of all Sudden Infant Death Syndrome (SIDS) deaths are that of premature infants [3]. Additionally, the highest prevalence of malaria cases, particularly deaths, exist among children below the age of 5 (90%), representing the main cause of child mortality in Africa [4].

1.2 Motivation

Mothers from low-income settings cannot afford the cost of keeping their premature babies in clinical incubators. This proposed solution will be cost-effective for such mothers. The project is also aimed to reduce SIDS caused by babies rolling to the side and sleeping on their stomachs. It will further be designed to reduce baby mortality caused by malaria.

1.3 Proposed solution

In order to address some of the factors leading to infant mortality, help save lives by providing warmth to premature babies and improve on the existing premature incubators, this project is aimed to design and implement a simple, cheap and portable premature baby incubator that can maintain the required temperature of 37°C continuously.

1.4 Contribution

This project seeks to bring the following contributions to the problems of premature infant death:

- Provide continuous warmth for premature babies at an affordable cost in a portable and in a family-friendly setting.
- The incubator will help reduce preterm death caused by malaria.
- The power consumption from the battery will be monitored and the battery can either be recharged through solar power or electricity from the grid.
- No swaddling or wrapping of the baby will be needed all the time in order to make the baby comfortable, yet rolling on the side and sleeping on the stomach will be avoided. This is to reduce SIDS caused by facedown sleep.
- Weight sensing which is vital in monitoring the growth of the baby will be included in the project.
- Sensors will be incorporated to monitor environmental conditions, and the information will be visible to both mother through a display and wirelessly to the Pediatrician.

CHAPTER 2: LITERATURE REVIEW

2.1 Background to the research

Causes of death for premature babies can be as a result of many factors, and one is the inability to control and maintain their body temperature [14]. Every year in developing countries, approximately 20 million premature and low birth weight babies are born, 4 million die within their first month and such deaths occur because traditional incubators are unreliable or inaccessible [1]. Premature babies make up 25% of all births in developing countries and are usually born outside of a hospital [15]. Mothers from low-income settings cannot afford the cost of keeping their premature babies in clinical incubators.

On the other hand, Sudden Infant Death Syndrome (SIDS), the sudden death of a child under the age of 1 remains unexplained after a full investigation into the autopsy and death scene. SIDS is typically associated with a sleep cycle, and risk factors such as prone/face-down sleep, bed sharing, soft bedding, and over-bundling in the sleep area. SIDS remains the leading cause of post-neonatal infant mortality in the United States, with an overall rate of 0.40 SIDS deaths per 1,000 live births despite national safe sleep initiatives [8]. As is currently the case in developing countries, infants in Finland used to sleep in the same bed as their parents, and a professor of Finnish and Nordic history at the University of Helsinki recommended that they stop. As a result, a tradition that dates back to the 1930's has been established to give all children, regardless of background, an equal start to life through the provision of a cardboard box to expectant mothers with a mattress in the bottom that becomes a baby's first bed. Through this, Finland has one of the lowest infant mortality rates [9].

Malaria is another cause of infant mortality that needs critical attention when it comes to infant mortality. According to World Health Organization [10], "Every 2 minutes, a child dies of malaria. And each year, more than 200 million new cases of the disease are reported. Although countries have dramatically reduced the total number of malaria cases and deaths since 2000, progress in recent years has stalled. Worryingly, in some countries, malaria is on the rise". As a result, infants most especially premature babies in this instance should not be exposed to mosquito bites. This can be achieved by the usage of insecticide-treated mosquito net.

2.2 Survey of related works

The problem of infant mortality and in particular that of premature infants has been studied extensively. A major contributor to neonatal mortality and morbidity throughout the world is hypothermia which is clinically defined as body temperature below 36.5 degrees Celsius [14]. For neonatal survival, a well-regulated thermal environment is essential [5]. The purpose of temperature monitoring is to keep the child in a thermoneutral environment [6]. Even though advanced incubators currently exist, they are costly to meet the needs of developing countries [4]. As such, there has been numerous innovative attempts geared towards increasing the survival rates of premature babies in developing countries. In order to address the availability and accessibility of incubators, the innovations below were developed. These related works were chosen because they have at least one of the motivations for this project.

2.2.1 Embrace Infant Warmer

Embrace Innovation is a medical innovation company with the goal of creating and supplying emerging markets with advanced, affordable, and reliable medical devices. Their first product is a low-tech infant warmer; a portable, low-cost incubator to reduce the risk of death in preterm infants in developing countries. The Embrace Infant Warmer is small and light and appears like a tiny sleeping bag and is easily transported to rural villages. It requires a phase-change material, a special wax-like material capable of maintaining a constant temperature while still providing the baby with heat. It enables the infant warmer to stay at a constant temperature (98.6°F/ 37°C) for up to 6 hours to sustain the baby's body temperature. After four hours, the infant warmer can be re-warmed by immersing it in boiling water for few minutes [11]. The limitations identified with the product are that the babies have to be swaddled to provide warmth leading to less comfortability for the babies. It does not provide warmth continuously. It has no monitoring function and is expensive with a cost of $300 to mothers in low-income settings.

2.2.2 Inflatable Incubator

A graduate from Loughborough University, James Roberts created a manually inflatable incubator which is warmed by using ceramic heating elements. It has a screen that displays the temperature and humidity dependent on the baby's age, an alarm that sounds if the required temperature changes and a phototherapy unit for babies suffering from jaundice. It is similar to a modern incubation system and costs £250 to manufacture and test. The device can be collapsed for transportation and runs off a battery that lasts 24 hours, in case of power unreliability. The incubator complies with British incubation standards, delivering a stable heat environment, humidification and jaundice lighting[12]. It is expensive to mothers in low-income settings and the design is not family-friendly.

2.2.3 The IncuLight: Solar-powered infant incubator

IncuLight is a solar-powered infant incubator that has two major objectives. The first is to design and build a light-weight and compact incubator and the second, to integrate solar panel(s) to power the incubator. The design was finalized as a readily powered, portable and low-cost incubator which can be implemented in a developing country. The structural design of the incubator focused on durability and portability. A luggage was used for the base of the incubator with a tent-like cover made of clear, washable plastic. Collapsible and lightweight supports hold up the tent. The incubator has two DC heaters that can be powered by main-line power when available or by a battery, which was charged by a solar panel. The heaters can maintain a steady 34-37°C temperature range within the incubator [13]. Its main limitation is cost with prototype cost estimation of $ 506.97.

2.2.4 An early stage prototype of a neonatal incubator for poor settings

Olson and Caldwell designed an early stage neonatal incubator for poor settings to reduce neonatal deaths caused by hypothermia. Automotive parts were used for the design because automobiles are prevalent throughout the world, especially in poor countries. The prototype was iterated to perform seven tasks namely; create a thermal-enhanced space for newborns, preserve a clean air environment, deliver ready visibility of newborns, allow comfort of both routine and emergent access, inspire healthcare providers in low provider-to-patient settings, ease transport and produce a power reservoir to account for brownouts and blackouts. It is constrained by the use of only automative parts to improve the sustainability and scalability of the device[14]. Another limitation identified is the heat source that produces light which is directed towards the baby. This can be harmful to the baby's eyes.

2.2.5 Transportable infant incubator for developing countries

Cichocki, O'Laughlin, Midouin and Busha presented a transportable infant incubator for developing countries. The proposed solution was presented using computer aided design. The design of the heating and ventilation system includes four car headlight bulbs to function on a 12V car battery and to dissipate 55W. It was assumed that the 12 V car battery will provide enough heat to produce rise time and response comparable to incubators in the market. It will operate by the use of a simple computer fan to blow air through the aluminum ducts [15]. It is limited by testing and verification of the design which was added as part of the future work.

2.3 Scope of work with relation to research

2.3.1 Provision of continuous warmth

The most crucial necessity of premature baby incubators is the provision of warmth and this incubator also considers that as a primary feature. This project seeks to provide this at a reduced cost compared to the other low-cost incubators. One of the drawbacks of the embrace incubator is the provision of warmth at a set number of hours. This incubator will control and maintain the body temperature continuously and, as such, employs the use of a rechargeable battery. The power consumption will be monitored with a battery level indicator to ensure continuity of power supply to the incubator. Just as the IncuLight which is solar-powered, this incubator's rechargeable battery will have the option of being powered by solar energy or through electricity from the grid.

2.3.2 Reduction of SIDS

SIDS is typically associated with a sleep cycle, and risk factors such as prone/face-down sleep, bed sharing, soft bedding, and over-bundling in the sleep area [8]. The fact that the incubator will be in a form of a bassinette hence functioning as a crib implies that bed-sharing will be avoided. The material to be used in the bedding will be hard but yet comfortable to sleep on. As compared to the Embrace incubator where the baby has to be swaddled, there will be no need for swaddling nor over-bundling needed while providing warmth to the baby. The required dimensions employed in the design of the incubator will avoid instances of the baby rolling and having a face-down sleep.

With regards to the avoidance of bed-sharing, Finland achieved a rapid reduction in infant mortality rate after adopting the tradition of providing cardboard boxes with a mattress.

Figure 1 shows the infant mortality rate in Finland from 1936 to 2010 per 1,000 births. The vertical axis is the number of mortality and the horizontal axis is the year.

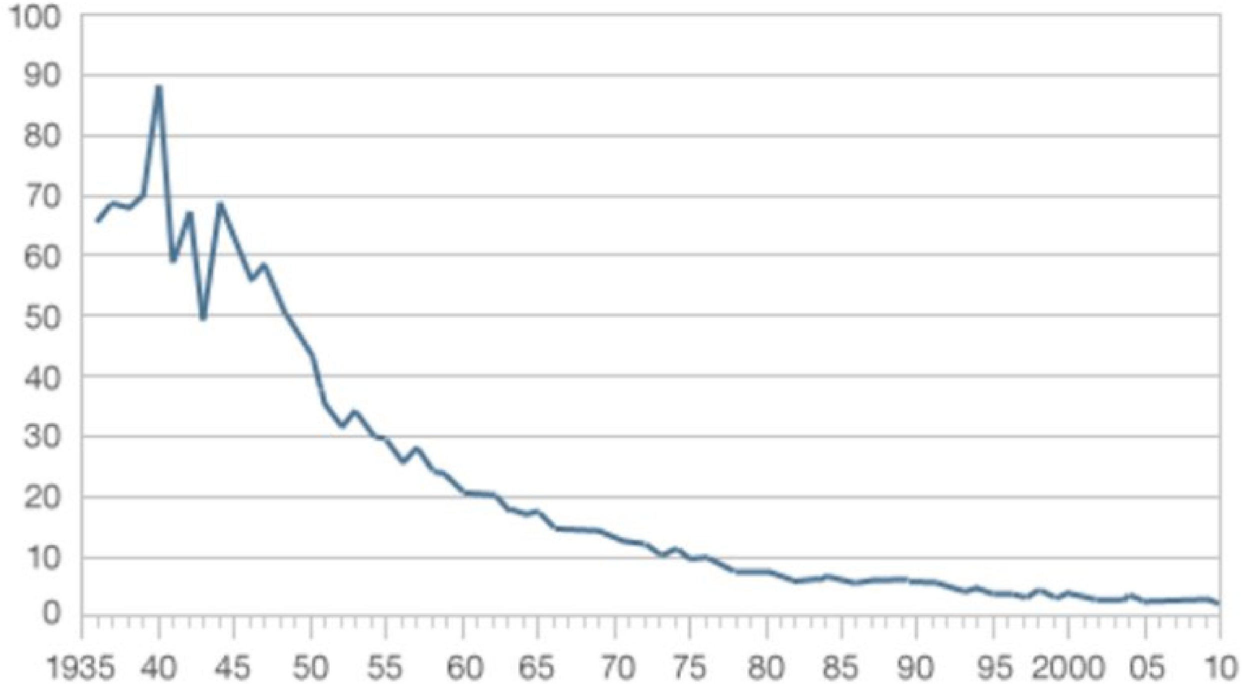


Figure 2.1*:* Infant mortality in Finland Source: Statistics Finland [9]

The choice of material for the mattress is a necessary factor to reduce SIDS. Latex foam is firm and comfortable to sleep on but unfortunately can emit toxic chemicals such as formaldehyde, naphthalene and benzene when heated which will be harmful to the baby's health [16]. Buckwheat hulls have been proven to promote better sleep, reduce snoring, provide muscle support and promote air flow for cooler sleep. It is also durable, adjustable, hypoallergenic and dust mite resistant. When heated it does not produce harmful substances [17]. Hence, buckwheat hulls will be used for the mattress of the incubator.

2.3.3 Reduction of malaria

Following the 2016 malaria contingency plan in Rwanda, severe malaria and mortality cases have since declined by 50% [7]. The contingency plan was put in place in 2016 and it included a mass distribution of bed nets for most vulnerable groups (pregnant women and family with children under one year of age). According to the World Health Organization [10], "there has been estimated reduction in the country's malaria burden with 430,000 fewer cases recorded in 2017 than in 2016". For the newborns that can be affected by the use of insecticide spray and applying insecticide creams on their delicate skins, the most effective and safe way to prevent malaria is through the usage of mosquito net. As such, this incubator will be designed to have a long-lasting insecticide-treated mosquito net over it aimed at reducing malaria.

CHAPTER 3: DESIGN METHODOLOGY

3.1 Standard incubator specifications

This project was designed by taking into consideration the standard incubator specifications. The standard incubator has over temperature protection and as such has an automatic cutoff of heater at 39.3 °C. It has audio and visual alarms. These alarms operate when the baby's temperature is Low/High (±5%), air temperature is Low/High (±5%), temperature probe failure, system failure, heater failure, low battery and main power failure. It also displays the baby's temperature, air temperature, set temperature and AC power on a Liquid Crystal Display (LCD).

3.2 Requirements

3.2.1 User requirements

The system should be responsive to user input. It should go off or on when the switch is pressed. The temperature value display should be visible to the user. The battery consumption indication should be visible and comprehensible to the user. The sound produced by the audio alarm should be heard by the user.

3.2.2 Technical/System Requirements

The system should work when there is no main electricity. The battery should be rechargeable using energy from the grid or solar energy. It should be energy efficient, portable, cost-effective, wireless and should detect and indicate battery consumption level. It should also indicate fault and should be deployable quickly while maintaining the set temperature continuously.

3.2.3 Design Requirements

The designed system consists of the main components namely; the bassinette, heating element, energy source to provide continuous energy in order to maintain a constant temperature of 37°C and the communication component.

3.2.3.1 Tables of material and electronic components selection

The bassinette is the component that the baby will be placed in. It should have the features to accommodate the baby safely. Figure 3.1 has the different options that can be used as the bassinette and their pros and cons.

Table 3. 1: Options for Bassinette

Bassinette			
Cardboard		Basket	
Pros	**Cons**	**Pros**	**Cons**
Cheaper compared to basket	Not durable because it can get wet when soaked with water	Portable, Durable, and Attractive	Cost more than cardboard

The heating element will produce the heat needed to regulate the baby's temperature. Table 3.2 has the different options that can be used as the heating element and their pros and cons.

Table 3. 2: Options for Heating element

Heating element					
Metallic		Chemical reaction		Infrared Light bulb	
Pros	**Cons**	**Pros**	**Cons**	**Pros**	**Cons**
Easily regulated.	Reacts in the presence of moisture.	Cannot be controlled when reactions starts. Also, it is not reversible.	Can be inconvenient to some users. It might produce gases that will be harmful to the baby.	Minimal cost	The light produced can affect the baby's eyes.

The power supply is one of the crucial components of the system. The pre-mature baby incubator can only function when powered. The energy source will provide the energy needed to heat up the heating element and also to power other components of the system. Table 3.3 has the different options that can be used as the energy source and their pros and cons.

Table 3. 3: Options for Energy source

Energy source			
Solar		ECG supply	
Pros	**Cons**	**Pros**	**Cons**
Favorable for the rural areas. It also has less running cost.	It has high initial cost(consists of solar panel, inverter, battery pack, charge controller, etc). Also, it is not reliable during the rainy season.	Reliable especially with a battery pack.	Issue with light out.

The communication component is responsible for transferring the information from the system and its environment to the Pediatrician. Figure 3.4 has the different options under the communication component and the pros and cons.

Table 3. 4: Options for Communication component

Communication			
Non wireless		Wireless	
Pros	**Cons**	**Pros**	**Cons**
Has less negative effect on health.	Limited distance for monitoring.	Helps in monitoring over a long distance.	Emit harmful radiations which can cause diseases. It also needs internet connection.

3.2.3.2 Design decisions and requirements.

Based on the comparisons made using the tables above, the options selected are basket for the bassinette, metallic heating element, energy from the grid as power source with rechargeable battery as back up and wireless communication. Table 3.5 has the design requirements for the options selected:

Table 3. 5: Design requirements for options of main components

Selected option	Design requirements
Basket	It should accommodate the size and growth of the baby and should be strong.
Metallic heating element	It should be non-corrosive, Great resistor of electric flow (more resistance means more I^2R losses which is dissipated as heat). It should heat up within a short period of time when powered.
Battery	It should not be bulky, be efficient, rechargeable, durable and should provide the power needed to heat the heating element.
Wireless communication module	It should transmit the communication over the required range of distance and consume relatively less power.

The heating element converts electrical energy to heat energy. Nichrome wire is cheap and non-corrosive. It is a great resistor to electric flow. The more the resistance, the more I^2R losses which is dissipated as heat. It heats up within a short period of time when powered. Nichrome 80 wire with diameter of 28 gauge (0.0126 inches/0.32 mm) was used. The 28 gauge diameter has relatively very small diameter compared to the diameters of nichrome wire available. A smaller diameter has higher resistance. A higher resistance wire produces more heat for a given current flowing through it. Nichrome 80 composed of 80% nickel and 20% chromium is very stable. Due to its excellent adhesion properties of its surface oxide, it offers greater service life compared to other nichrome wire types. It is generally used for home appliances and industrial furnaces. Its applications include water heaters, soldering irons and ironing machines. Table 3.6 shows further properties of the nichrome wire used[18].

Table 3. 6: Further properties of the nichrome wire used

Maximum operating Temperature	**Resistivity @ 20°C (68°F) Ω mm2/m (Ω/cmf)**	**Oxidation Resistance**
1180°C (2150°F)	1.09 (656)	High

A pugh matrix was used to evaluate and select the specific communication module using Bluetooth module as the baseline for the others; GSM module, Wi-Fi module and LoRaWAN module.

Table 3.7: Pugh matrix for communication unit

Criteria	Baseline	Weight	A	A1	B	B1	C	C1
	Bluetooth module		GSM module		Wi-Fi module		LoRaWAN module	
Availability	0	7	0	0	1	7	-1	-7
Cost	0	6	-1	-6	1	6	-1	-6
Energy efficiency	0	5	-1	-5	1	5	1	5
Coverage area	0	4	1	4	1	4	1	4
Security	0	3	-1	-3	-1	-3	-1	-3
Complexity	0	2	-1	-2	1	2	-1	-2
Size	0	1	-1	-1	-1	-1	-1	-1
Total				-13		20		-10
Selection legend: better =1 same = 0 worse = -1								
Selected: Wi-Fi module								

3.3 Methods

3.3.1 Block diagram

Figure 3.1 illustrates the block diagram of the proposed solution.

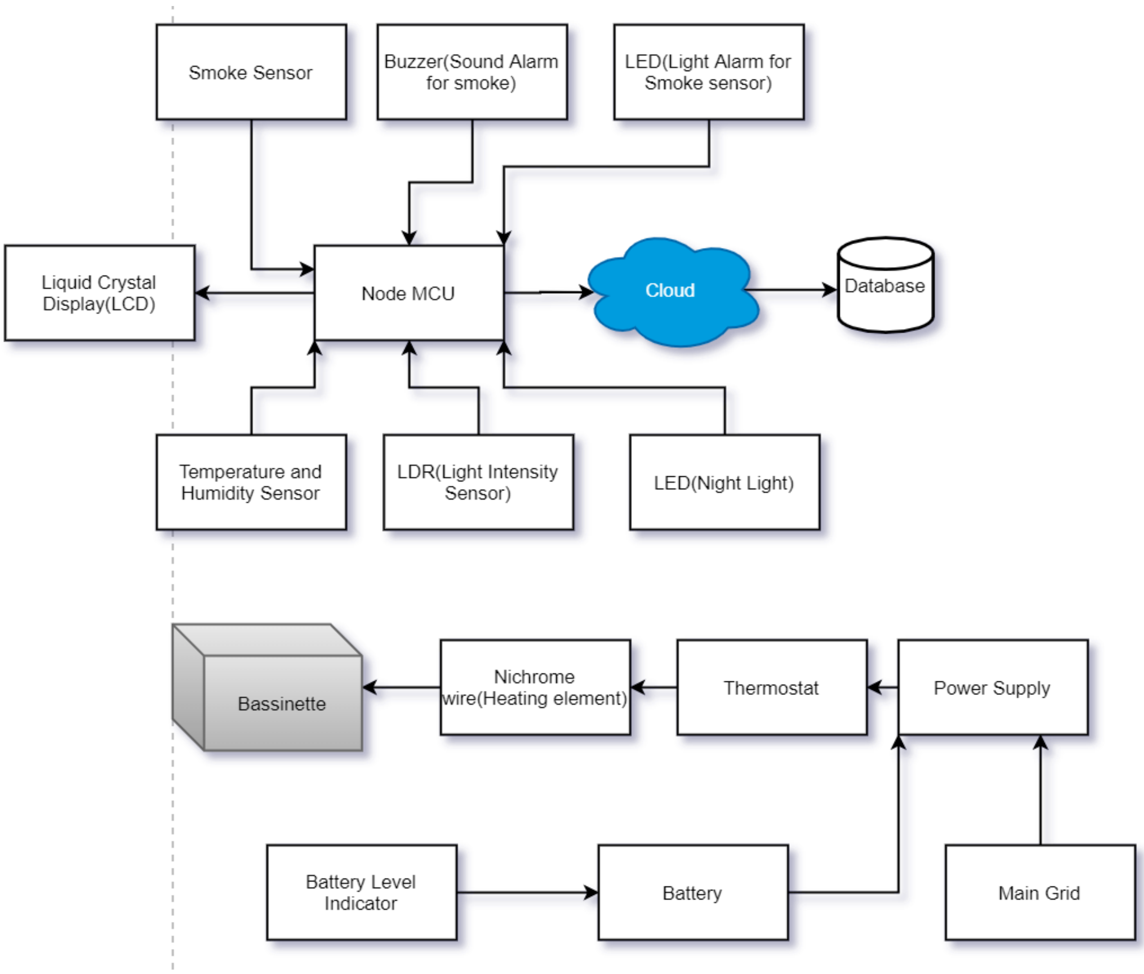


Figure 3.1: Block diagram for the proposed solution

The different sensors for monitoring are connected to the programming and communication component, Node MCU(ESP8266 Wi-Fi Module). The environmental conditions monitored by the sensors are displayed on the Liquid Crystal Display (LCD) for the user(mother) and then sent wirelessly to a database where the Pediatrician can gain access to. The incubator's bassinette has the heating element (nichrome wire) incorporated in it to produce the heat and it is regulated by a thermostat. In order to produce the heat, the heating element is powered by power from the main grid or battery. To ensure continuous supply of energy for the suitable incubator's temperature to be constantly maintained, the battery when being used as alternative power supply will be connected a battery level indicator.

Figure 3.2 presents the electrical component layout of the proposed solution using Fritzing software.

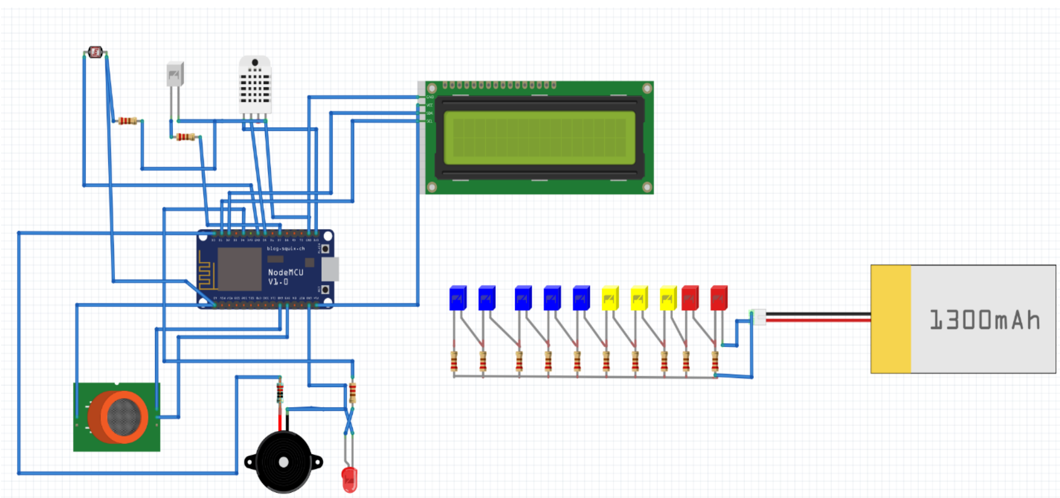


Figure 3.2: Electrical component layout for proposed solution

The Node MCU(ESP8266) is a complete and self-contained Wi-Fi networking solution and acts as a microcontroller [2]. It is employed because it acts as both a processing and communication unit. The temperature and humidity sensor (DHT 22) is a low-cost digital temperature and humidity sensor which uses a thermistor and a capacitive humidity sensor to measure the neighboring air and produces a digital signal on the data pin. The LCD used for the project is 12C 12×2 character. It is cost effective, has less limitation in displaying special and custom characters and easy to program. In this project, it displays the temperature and humidity, the smoke level using the sensor, MQ-2 and light intensity. The LEDs used for the battery indication consumption is designed using different colors to depict low to high voltage.

3.3.2 Circuit Diagram

Figure 3.3 shows the circuitry of Figure 3.2 using Fritzing software.

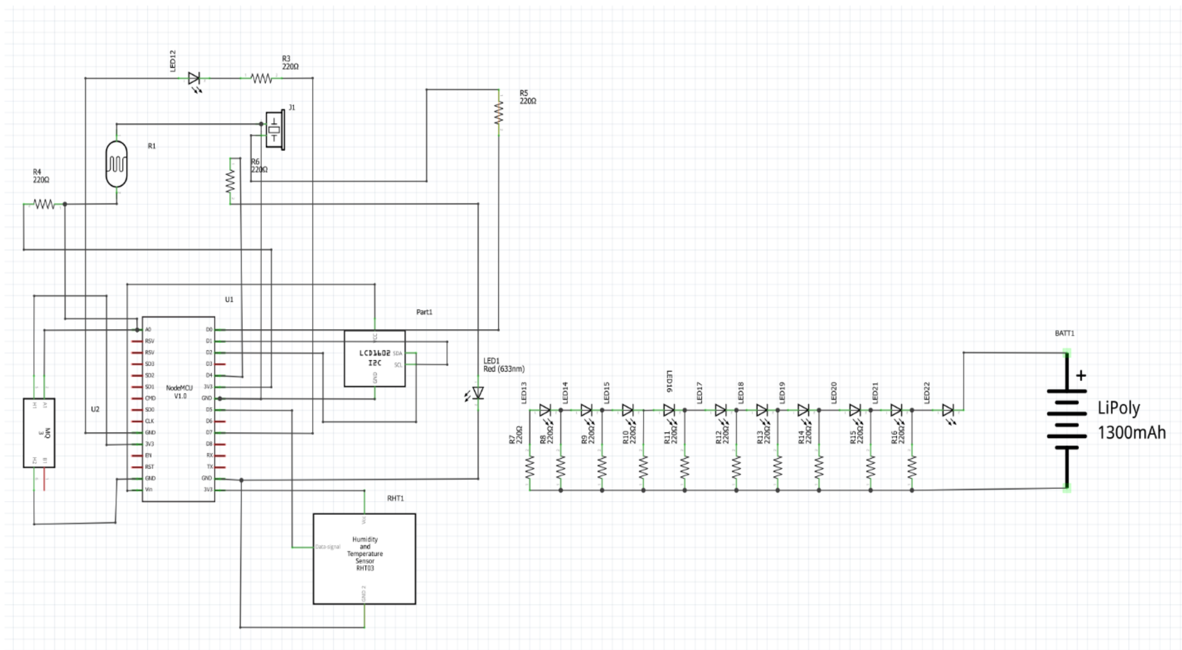


Figure 3.3: Circuit diagram of proposed solution

3.4 Preliminary heat tests

In order to understand the design of the heating component of the incubator, tests were conducted. This is to identify the range of temperatures that will be suitable to provide the warmth required, how long it takes to heat to a particular temperature, the duration it maintains the temperature when the power supply is detached and ultimately, the amount of voltage and current that will be required.

The materials used for the experiments included the nichrome wire for producing the heat, copper wire for connecting the ends of the nichrome wire to the power source, power supply for providing the energy source, Vernier Lab Quest 2 and temperature probe for determining the temperature and graphs, battery as backup power supply, multimeter for determining the resistance, voltage and current of the battery before and after discharging, a mini circular basket (bassinette) and buckwheat hulls sewn in a cloth (mattress).

During the tests, bare hands were used to feel the heat produced by the nichrome wire. Even though the hand was used to identify the temperature that will be provide the comfortable warmth needed, safety precaution was taken in order to avoid burns. Temperature values on the lab quest was read before the palm was placed on the nichrome wire to detect the warmth produced.

3.4.1 Test 1

The first test was done using the battery for the backup supply. An Uninterruptible Power Supply (UPS) battery was used as the energy source. This was to confirm the expectation that 12V battery will be enough to heat the nichrome wire. For the initial tests, the nichrome wire was coiled on a circular shape hard paper(insulator) and sewn to provide firm attachment using thread as shown in Figure 3.4:

Figure 3.4: An image of the nichrome wire being sewn unto the paper

The actual voltage of the 12v battery was determined using a multimeter and gave a value of 11.93V. When it was connected to the nichrome wire for five minutes, it did not produce significant warmth. The battery was disconnected, and the voltage determined again. The voltage had a sudden drop to 11.06V. The conclusion drawn from the first test showed that 12V was not enough to heat up the nichrome wire to a significant temperature value.

3.4.2 Test 2

The second test was conducted using direct power supply. The voltages were varied to identify its effect on the nichrome wire. The test was set up as shown in Figure 4.4:

Figure 3.5: An image of the set up

At 12V and after 5 minutes, the voltage was 24.7℃ and after 15 minutes was 25.1℃ while increasing to 25.2℃ after 20 minutes. This temperature was far below the temperature needed so the voltage was increased to 13V. At 13V and after 5 minutes, the temperature increased to 49.6℃. This temperature was comfortable to touch and needed to be increased in order to heat up the buckwheat hulls when placed on top of the heating element. Hence, the voltage was increased to 15V and after 5 minutes, it gave a temperature of 49.6℃. After 10 minutes, it became uncomfortable when touched and the buckwheat hulls was placed on it. It then increased to 69℃ after 30 minutes but the temperature on the surface of the buckwheat hulls was insignificant. The voltage was therefore increased to 20V and after more than an hour, the warmth on the surface of the buckwheat hulls could be felt a little bit more than the body temperature. The highest temperature of the nichrome wire at 20V was 76℃.

3.4.3 Test 3

The third test was done using different lengths of nichrome wire; 5cm,10cm and 15cm. This was aimed at identifying the effect of length on the heat test. The resistances of the three lengths were checked using multimeter and even though it gave continuous values, it was determined that the longer the length of the wire, the higher the resistance. This can be explained theoretically that the current has to travel more distance when the length of the wire is increased hence facing more obstacles(resistance). With this test, the current was varied to determine its effect on temperature. There was no substantial difference in the changes in temperature values when the different lengths of nichrome wire were powered at different currents. The current values produced were 0.5A, 0.6 A, 0.7A, 0.8A, 0.9A, 1A, 1.25A giving average temperature values of 26, 30, 35, 37, 40, 43 and 49 respectively. At 3A, the nichrome wire was red hot. From this finding, it was expected that the effect of current changes will be same for the sewn nichrome wire. After connecting the sewn nichrome wire, it demanded more current to get the temperatures compared to the straight nichrome wire. This was because the thread used to attach the nichrome wire to the paper as well as the paper absorbed some amount of the heat.

CHAPTER 4: IMPLEMENTATION, RESULTS AND DISCUSSION

4.1 Battery Consumption Detection

The power supply is one of the crucial components of the system. The pre-mature baby incubator can only function when powered. Power supply from the grid is used as the main source of energy and the battery used as back-up. In rural communities where there is not electricity, the battery will serve as the main source of energy. In both cases, it is important to detect the battery consumption in order to ensure power supply to the incubator at all times. As such, a battery level indicator was incorporated into the proposed solution. As designed using software before implementation, the circuit consists of ten Light Emitting Diodes (LEDs) and ten resistors to resist the flow of current. When the battery is fully charged, all ten LEDs come on. The LEDs begin to go off starting from the blue colored LEDs when the battery begins discharging. All five blue LEDs going off informs the user (the mother) that the battery is 50% discharged. Yellow depicts that the battery is tolerable. When only red LEDs are on, the battery is critically low and needs to be recharged. A Tenma switching mode power supply was used to vary the voltage to test the battery level indicator starting with the maximum voltage, 25V. Figure 4.1 shows the working of the battery level indicator.

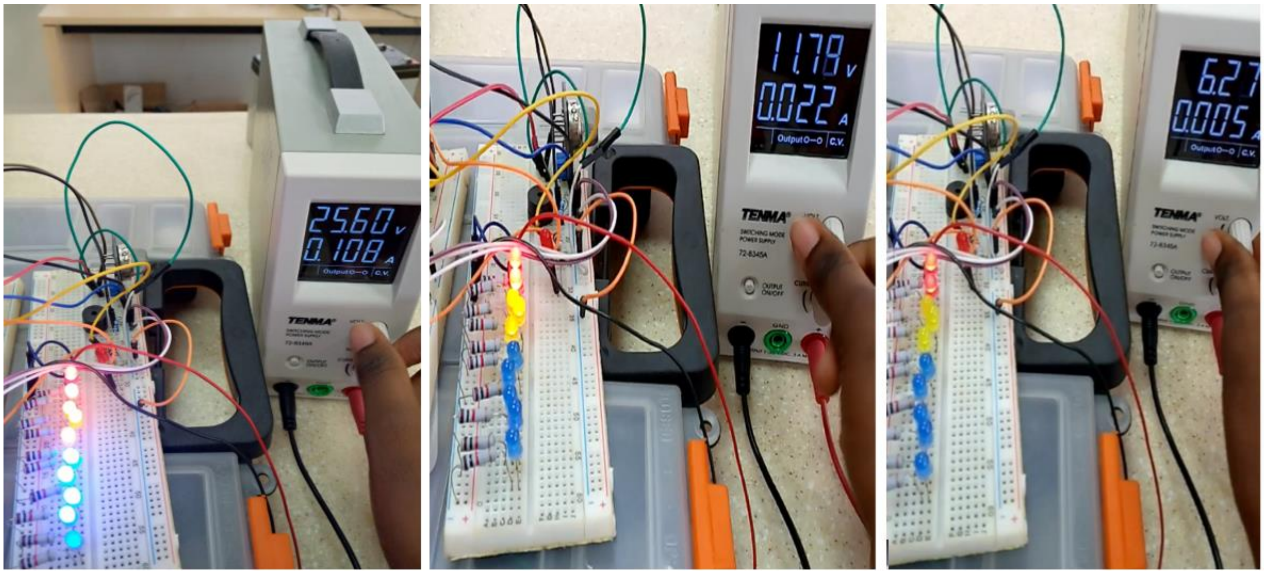


Figure 4.1: The lights go off as the voltage reduces starting from the blue LEDs.

4.2 Monitoring using sensors

4.2.1 Temperature and Humidity

The temperature and humidity values are used in three areas for the system. The values are displayed on the Liquid Crystal Display (LCD) for the user (the mother) to know the environmental temperature at a particular point in time. It is also sent to the database for the Pediatrician to have knowledge of the environmental temperature that the baby is situated at. Finally, it is used by the system to regulate and maintain the temperature recommended. A low environmental temperature detected by the sensor allows the thermostat to increase the temperature of the heating element(nichrome wire) to bring it to the set temperature and vice versa.

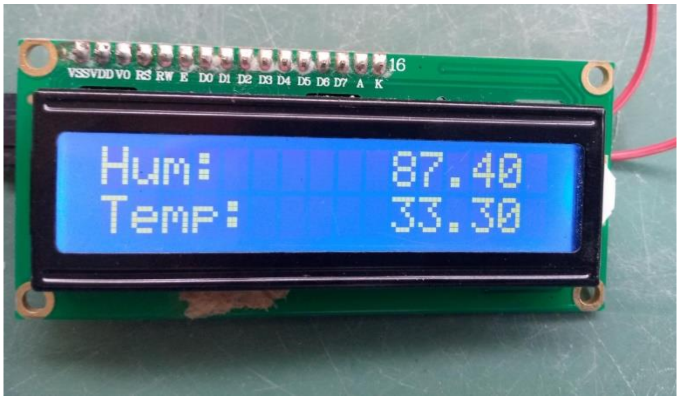


Figure 4.2: A display of the temperature and humidity on the LCD

4.2.2 Light Intensity

The values of the light intensity is communicated to both the mother and sent to the database for the Pediatrician. The light dependent resistor is programmed to turn on the night light when darkness is sensed.

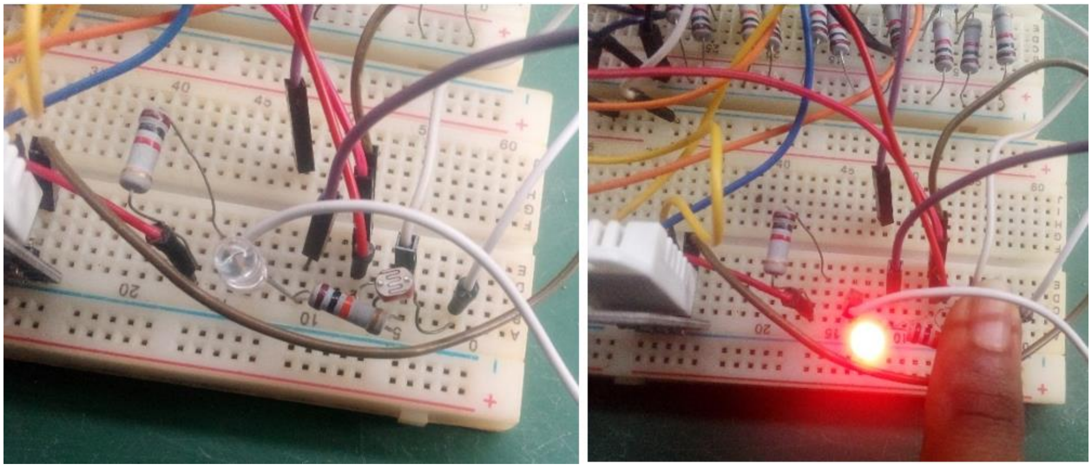


Figure 4.3: A representation of how the night light functions

Figure 4.4: A display of the smoke level and Light Dependent Resistor value

4.2.3 Gas level(smoke) Detection

As an open incubator, it will have continuous supply of oxygen from the environment to the baby. There may be presence of toxic gases which may cause threat to the life of the premature baby. In this project, the MQ2 gas sensor is used to detect the harmful gases such as LPG, Smoke, Hydrogen, Carbon Monoxide Concentration and Methane. In the rural areas, most mothers resort to firewood for cooking. Should the smoke from the fire source get closer the baby, the mother will be alarmed by sound and light from the incubator. Smoke was used to test the performance of the gas sensor in this system.

For the sound alarm, a buzzer is incorporated in the system to sound an alarm to the mother upon detecting the toxic gas. The sensor is programmed with the buzzer to sound an alarm after exceeding the threshold value. No sound occurs when there is no toxic gas detected.

For the light alarm, the light is incorporated in the system in addition to the buzzer to give a visual alarm to the user to take the needed action. The red light blinks to send the signal of danger after detecting the toxic gas, in this test, smoke.

The smoke level is displayed on the LCD for the user and also sent to the Pediatrician. The gas level when displayed depicts to the mother that the gas level is normal and unharmful to the baby. When a toxic gas is sensed, while the buzzer sounds and the red LED blinks, the LCD displays ‘alert’ instead of the gas level.

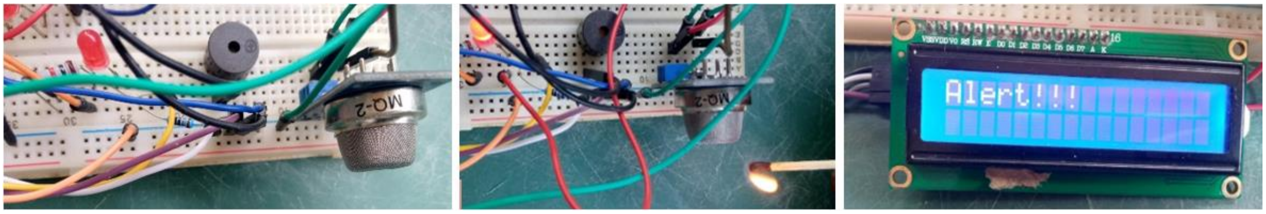


Figure 4.5: The red light blinks, the buzzer sounds and ‘Alert’ is displayed on the LCD screen when the smoke is sensed

4.3 Heat Implementation

After conducting heat tests under chapter 3 to advise the design of the heating component, it was implemented and further heat tests carried out to determine its performance.

Figure 4.6 shows some stages taken to create the final heating component of the incubator.

Figure 4.6: Captures of some stages in implementing the heating element

A property that makes nichrome wire suitable as the heating element is its relatively high resistance to generate more heat. As such, the nichrome wire sewn on the cloth separately for the base and for the side of the bassinette were connected in series to achieve higher resistance as shown in Figure 4.7.

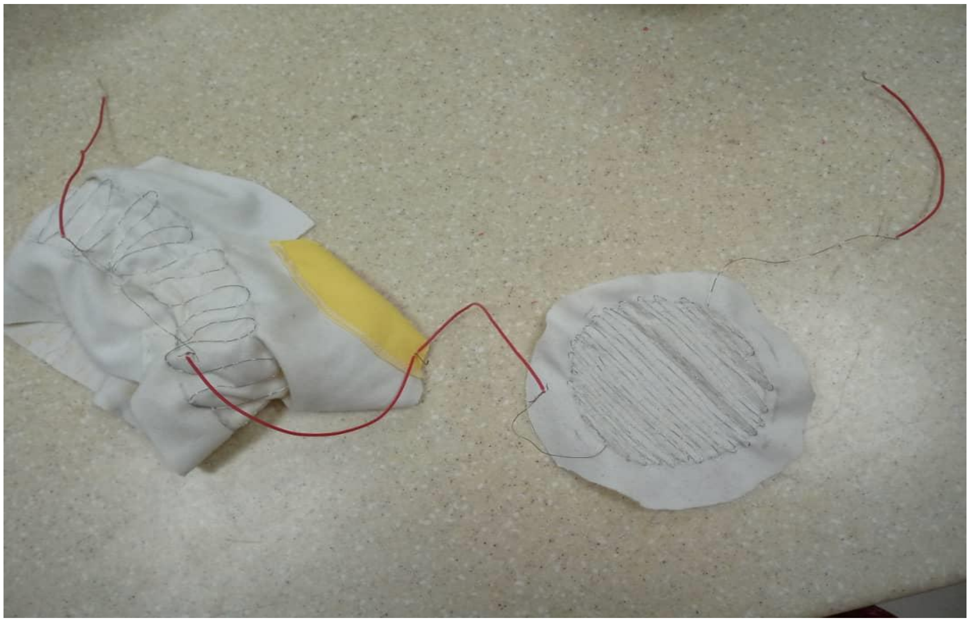


Figure 4.7: Sewn nichrome wire connected in series

The nichrome wire for the side was coiled and sewn spaced out as compared to the part for the base. This is because less heat is needed at the side compared to the base which needs to conduct the heat through the mattress to the surface. The heating component was connected to a power source and heat tests carried out using temperature probe and Lab Quest. The graphs of the temperature with time for the side and for the base proved the assumptions made to be correct. The nichrome wire sewn at the side had higher temperature than at the side.

The final heat test was conducted with the mattress on top of the heating element and powered to identify if the temperature needed, 37℃ on the surface of the incubator will be acquired. At approximately 20V and 1.4A, the temperature attained on the surface of the required temperature was 37.2℃ as in Figure 4.8.

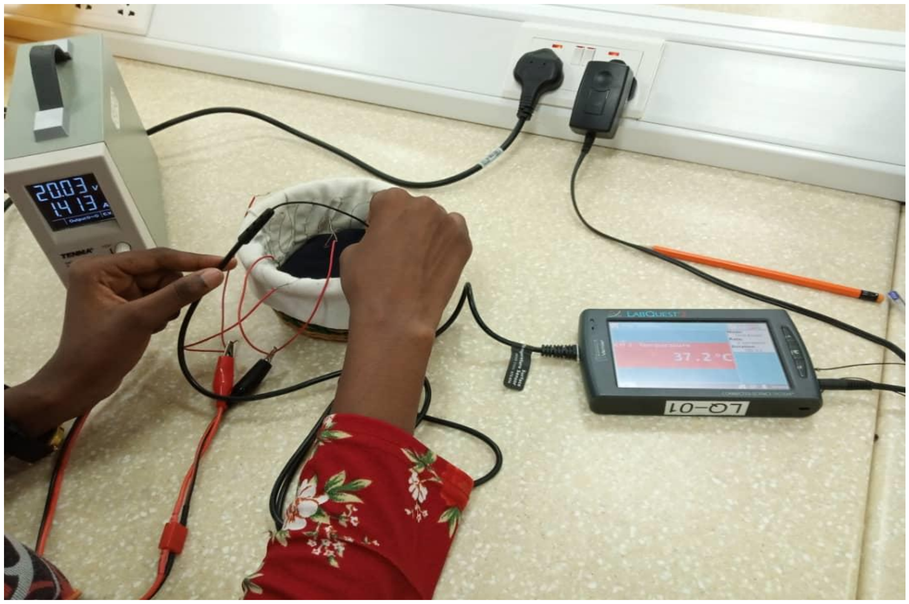


Figure 4.8: Reading temperature values from the surface of the mattress.

Increasing the voltage increased the temperature on the surface of the mattress. The temperature at 37℃ was maintained for 1 minute after the power was disconnected after which the temperature began to drop gradually.

In an environment with lower temperature compared to the environment in which the test was carried out, the heating element will have to heat to a higher temperature in order to keep the incubator temperature at 37℃. As such, more voltage will be needed to supply the amount of energy. A 25V rechargeable battery with 6Ah rating is suitable to power the incubator to a temperature of 37℃ and above. The calculation below shows an estimation of how long the battery will last when powering the incubator assuming the temperature is set to 37℃ in which case the current is approximately 1.4A as shown in Figure 4.8.

$$Battery\ life(hours) = \frac{Capacity(Ah)}{Current(A)}$$

$$= \frac{6Ah}{1.4A}$$

$$= 4.29\ hours$$

Therefore, the battery will last 4 hours, 29 minutes.

4.4 Heat regulation using MATLAB(Simulink)

A thermostat is needed to maintain the incubator at a set temperature. The thermostat was not available and in order to create the feedback loop for the system, the thermostat was simulated as shown in Figure 4.9.

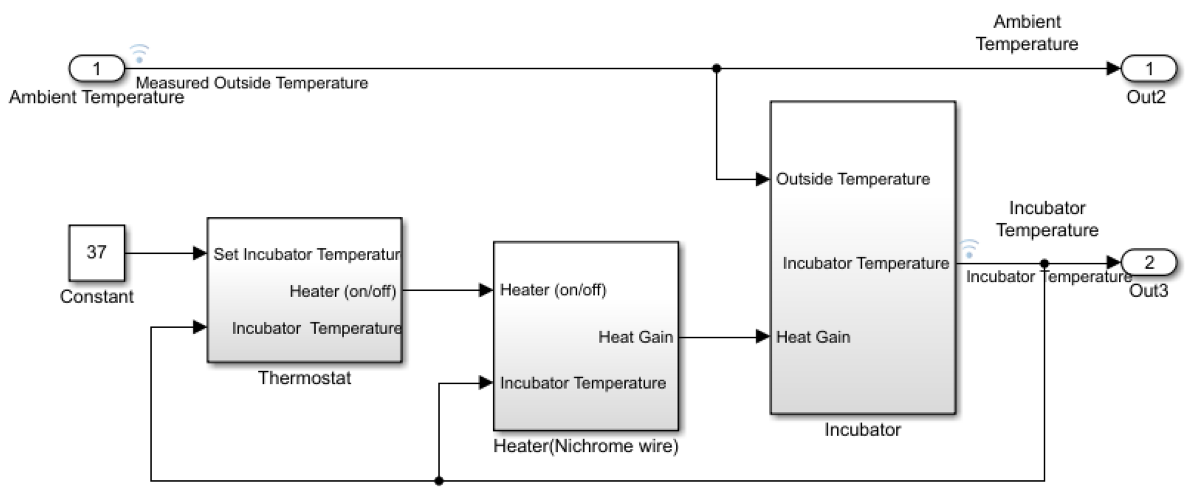


Figure 4.9: Model of the incubator heating system

The heating system was modelled to show how the changing ambient temperature affects the set incubator temperature. The model includes a heater (nichrome wire) controlled by the thermostat (controller model) to heat the incubator to the set temperature.

A set up was created to acquire ambient temperatures under different temperate zones. This is to illustrate how the incubator will maintain the set temperature under normal, cold and hot temperate zones. A temperature probe connected to a LabQuest was used to store the ambient temperatures. Temperature values were taken from a surrounding close to ice cubes, then under normal environmental temperature and then moved to a surrounding of hot air. This was done within a duration of 30.5 seconds. The data of the ambient temperature values with time was incorporated into the model and simulated. Figure 4.10 illustrates how the ambient temperature varies with the set incubator temperature remaining constant.

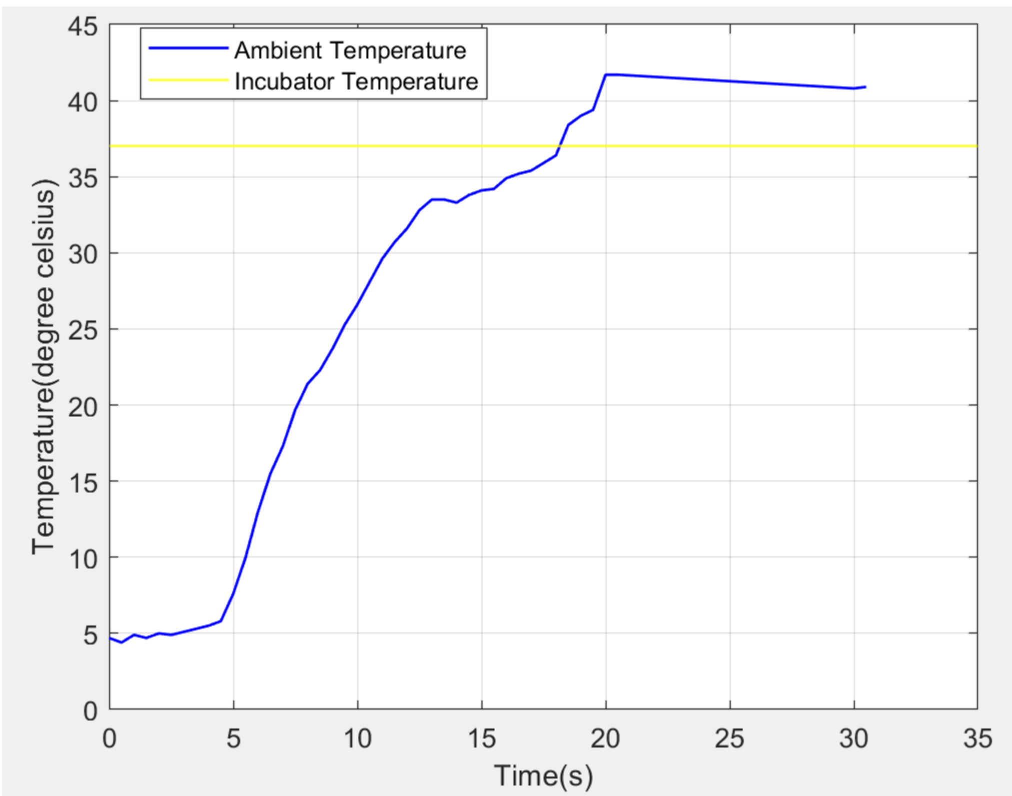


Figure 4.10: Simulation illustrating the maintenance of the set temperature as the ambient temperature varies.

4.5 Reduction of SIDS Implementation

In order to help reduce SIDS as stated in the project scope, the material used for the bedding was cautiously selected. Latex foam even though comfortable to sleep on, emits harmful chemicals and was therefore discarded. Buckwheat hulls was used to create the mattress for the incubator and upon heating, it did not produce any harmful gas as researched. The mattress was created by sewing a piece of cloth, filling it with the suitable amount of buckwheat hulls and then enclosed as shown in Figure 4.11.

Figure 4.11: The buckwheat mattress

The baby will be kept in the basket with the required dimension to reduce SIDS caused by the baby rolling, face-down sleep and bed sharing.

4.6 Reduction of Malaria Implementation

As specified in the literature review section, insecticide-treated mosquito net was chosen as the most efficient way to help combat malaria. Other options such as insecticide spray and insecticide cream can cause harm to the baby's delicate skin. The mosquito net in implementation was placed on top of the incubator to avoid mosquitoes from entering in. Figure 4.12 shows the incubator with the mosquito net over it.

Figure 4.12: Implementing the usage of the mosquito net

Figure 4.13 shows the overall hardware of the proposed solution

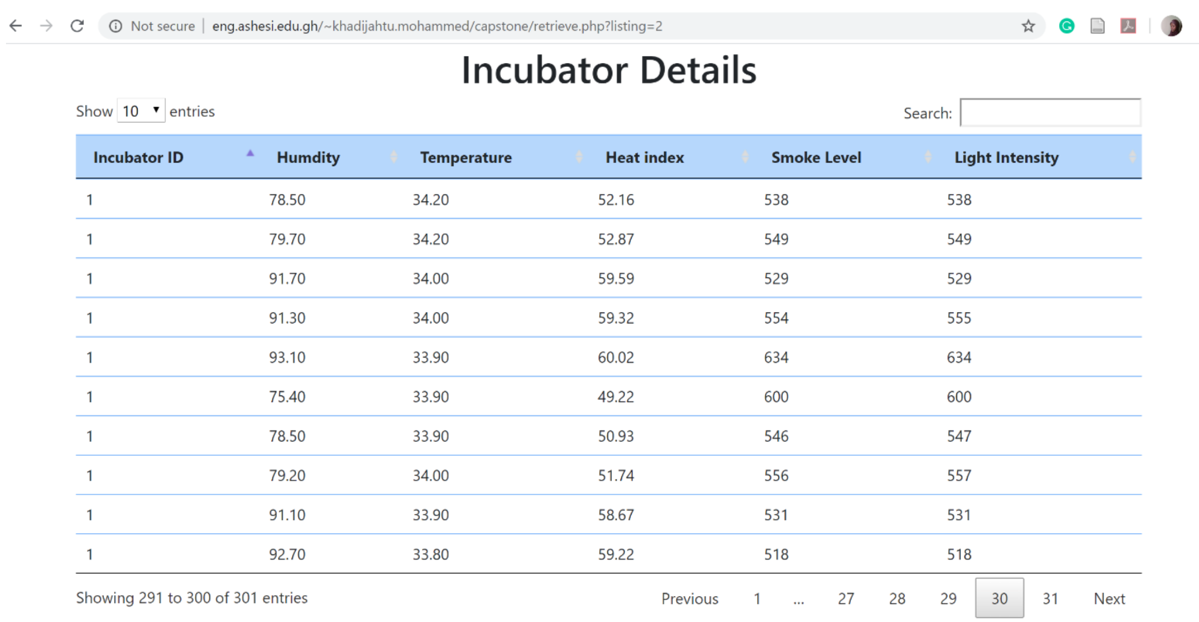
Figure 4.13: Overall hardware of the proposed solution

After the circuit is transferred onto a Printed Circuit Board(PCB), it needs to be cased in order to be attached on the outside of the basket. The casing for the electrical and electronic component was done using Solidworks as shown in Figure 4.14. The slanted side has the LCD screen with the light Dependent Resistor (LDR), the night light followed by the temperature and humidity sensor. It also has the smoke sensor, the buzzer and blinking light alarm in line. The other side of the circuit connection has the battery level indicator with the thermostat. The side with the LCD is slanted in order to easily read values on the screen when it is attached to the basket.

Figure 4.14: Modelled casing of the electronic components

4.7 Web Application

Another requirement of the system is to communicate wirelessly to the Pediatrician. It sends the incubator identity number and the environmental parameters namely humidity, temperature, heat index, smoke level and light intensity in real time as shown in Figure 4.15. The incubator ID is added to identify the incubators when the project is scaled.



Incubator ID	Humdity	Temperature	Heat index	Smoke Level	Light Intensity
1	78.50	34.20	52.16	538	538
1	79.70	34.20	52.87	549	549
1	91.70	34.00	59.59	529	529
1	91.30	34.00	59.32	554	555
1	93.10	33.90	60.02	634	634
1	75.40	33.90	49.22	600	600
1	78.50	33.90	50.93	546	547
1	79.20	34.00	51.74	556	557
1	91.10	33.90	58.67	531	531
1	92.70	33.80	59.22	518	518

Figure 4.15: Web Application displaying the environmental conditions of the incubator

CHAPTER 5: CONCLUSION, LIMITATIONS, AND FUTURE WORK

5.1 Conclusion

This premature baby incubator is cheap, wireless, portable and maintains the needed temperature continuously. It can be powered with power supply from the grid or battery. It comes with a battery level indicator to ensure provision of continuous energy to regulate the baby's temperature. It is designed to be family-friendly. It is a smart system that has sensors to detect temperature, humidity, toxic gas(smoke), and light intensity. It further displays the information to the mother via an LCD screen and wirelessly to the Pediatrician. The use of buckwheat hulls which does not produce toxic gas when heated will prevent facedown sleep which could cause suffocation hence reducing SIDS. The addition of insecticide treated mosquito net will help reduce baby mortality caused by malaria.

5.2 Limitation

There were challenges faced that reduced the scope of the project. Due to the COVID-19 pandemic, the unavailability of the engineering laboratory prevented the project from final stages such as soldering and packaging. As such, Computer Aided Design (solid works) was used to create the casing for the sensors to depict how it will look in actual casing. A thermostat was needed to set and maintain the incubator at a suitable temperature but due to its unavailability, it was simulated on MATLAB using Simulink. Similarly, the weight sensing could not be incorporated because of unavailability of the sensor and workshop. The design of how it would have been included into the system is described in the section, future work. The bassinette of the incubator is not to scale and as such cannot accommodate the baby, but the model was designed factoring all other conditions needed for the project to function as required.

5.3 Future Work

Several applications can be incorporated into the system to further improve it. One of the improvements is including weight sensing which is vital in detecting the growth of the baby. A 5kg load cell can be used in conjunction with HX711 to determine the weight of the baby which can be displayed on the LCD screen and also to the database for the Pediatrician. The load cell can be cased with wooden platform and the weight of the bassinette without the baby in, tiered. When the baby is put in the bassinette and placed on the weighing design, the weight of the baby will read on the LCD screen. The value displayed on the LCD screen is for the user(mother) and then transferred wirelessly to the Pediatrician. Noise detection can also be factored in to detect the cry of the baby and sound an alarm wirelessly to the mother. Breathing detection is another factor to improve this project. The breathing detector can be designed and placed under the mattress of the incubator. It will detect movement and when there is no movement detected, there will be an alarm to alert the mother.

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