DEVELOPMENT OF LOW-COST IOT BASED INFANT INCUBATOR IN TANZANIA: A CASE OF EAST AFRICAN COMMUNITY REGION

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A Project Report Submitted in Partial Fulfillment of the Requirements of the Award of the Degree of Master of Science in Embedded and Mobile System of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Physical adjustment to life outside of the mother's body of a baby might be 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, their operation cost is too expensive for low-income countries to obtain and it relies only on electricity for their operation. The fundamental goal of this project is to create an inexpensive, efficient, and dual-powered incubator that saves premature infants' lives. We developed the system which utilizes ESP32 as the Microcontroller Unit board interfaced with DHT22, a thermistor for skin temperature computation, MAX30102 to evaluate heart rate and oxygen saturation in the blood. An oxygen sensor measures the air quality in the chamber, and a ultraviolet 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 short messege services to medical personnel via Global System for Mobile Communication. The system adjusts the environment using a heater, humidifier, and oxygen valve. The final design was implemented on a Printed Circuit Board and tested after a circuit was designed and simulated. The sensors were calibrated against standard sensors to receive accurate measured data, and then transferred via Wi-Fi through the ESP32 to a webpage for remote monitoring and control. In conclusion, based on the test-performed the developed system can save the lives of premature babies, is low-cost, and is applicable in areas with limited resources. Furthermore, we recommend an easy way to assess the functionality of the locally developed systems by the regulatory institutions involved so as to be implemented successfully.

DECLARATION

I, Daniel Wilson Rwechungura, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation is my original work and that it has neither been submitted nor concurrently submitted for a degree or similar award in any other institution.

Daniel Wilson Rwechungura

3/8/2022

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Dr. Judith Leo

3/8/2022

Name and Signature of Supervisor 1 Date

Prof. Michael Kisangiri

Name and Signature of Supervisor 2 Date

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology, a dissertation entitled "*Development of Low-Cost IOT Based Infant Incubator in Tanzania: A Case of East African Community Region*" In partial Fulfilment of the Requirements for the Award of the Degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology.

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DEDICATION

I devote this work to my esteemed family: My mother Ms. Mary Daniel, my wife Ms. Joyce Timothy and my sons: Wilson and Winston.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF A0BBREVIATIONS AND SYMBOLS

CDC	Centers for Diseases Control and Prevention
CSS	Cascading Style Sheet
DCS	Distributed Control System
EGSM	Extended Global System for Mobile Communication
GSM	Global System for Mobile Communication
HTML	Hypertext Markup Language
IDE	Integrated Development Environment
IMR	Immature Mortality Ratio
IoT	Internet of Things
KCMC	Kilimanjaro Christian Medical Center
KMC	Kangaroo Medical Care
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MCU	Microcontroller Unit
MMR	Maternal mortality Rate
MoHSW	Ministry of Health and Social Welfare
MQTT	Message Queuing Telemetry Protocol
NICU	Neonatal Intensive Care Unit
PCB	Printed Circuit Board
SMS	Short Message Service
SPO2	Oxygen Saturation
UNICEF	United Nations Children's Fund
UV	Ultraviolet
WHO	World Health Organization
Wi-Fi	Wireless Fidelity

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Childbirth is both a delightful and a painful occasion. The woman and the baby both go through a lot of physical and emotional changes throughout pregnancy. A newborn physical adjustment to life outside of its mother's body, which can be difficult owing to health problems and other environmental variables, can be difficult.

Every year, an estimated four million babies die around the world, with the great majority of deaths taking place in underdeveloped countries. In addition, yearly one million neonates die in Sub-Saharan Africa with half of these deaths occurring within the first seven days of life (Lawn *et al.,* 2005). In 2006, the number of children dying before reaching their fifth birthday decreased to 9.7 million worldwide (United Nations Children's Fund [UNICEF], 2007). As of 2015, there were 395 000 newborn deaths in Tanzania, with a neonatal mortality rate of 21 per 1000 live births. The number of children dying has decreased considerably over the last five years as a result of government initiatives; nonetheless, the majority of the decline occurred after the first month of life, and neonatal mortality has remained stable (Ministry of Health and Social Welfare [MoHSW], 2015).

Worldwide Preterm delivery problems (35%) are the most common cause of neonatal deaths, followed by birth asphyxia (24%) which is the lack of oxygen and blood flow to the brain, and infections (sepsis, pneumonia and meningitis) (20%) (World Health Organization [WHO], 2006). In Tanzania, birth asphyxia (31%) is the greatest cause of neonatal fatalities, followed by preterm birth problems (25%) and infections such as sepsis and meningitis (20%), and pneumonia (5%) (Afnan-Holmes *et al.,* 2015).

Premature birth causes a large variety of complications (born before 37 weeks of pregnancy), have a low birth weight (less than 5.5 pounds), or a medical issue that necessitates constant monitoring. Nearly 5% to 18% of pregnancies are preterm birth and it is a key source of morbidity and mortality in infants (Romero *et al.,* 2014). Therefore, the majority of infants require special care after birth due to a variety of health issues caused by a variety of reasons and are admitted to the neonatal intensive care unit (NICU). According to Bouwstra *et al.* (2009), the NICU provides care for babies who are born prematurely and have complications during delivery or develop difficulties while still in the hospital as presented in Fig. 1. Premature or exceptionally small babies are placed in an incubator, which provides a regulated and protected environment for their care (Bouwstra *et al.*, 2009). Preterm birth affects 5% to 18% of pregnancies and is a primary cause of morbidity and mortality in infants, especially in Tanzania.

Figure 1: Neonatal Intensive Care Unit (NICU)

According to literature, the use of science and technology has improved neonatal care resulting in increasing survival rates. This can be clearly shown by the following statics; from 68 per 1000 live births in 2004/05 to 51 in 2010 and 45 in 2013, the infant mortality rate (IMR) has declined. By 2014, the IMR had dropped to 38 fatalities per 1000 live births, surpassing the 2015 target of 46 deaths per 1000 live births (Alkema *et al.*, 2014). With these promising results through the use of ICT, this project aims at overcoming the aforesaid issues through the use of emerging technologies that have not been innovatively deployed in the area especially to feature the need of underdeveloped countries' settings such as Tanzania. Therefore, this project aims at designing, developing, and validating a low-cost multi-powered IoT-based infant incubator that will ensure an increase in infants' survival rate by providing them with the necessary healthy environment. The design aims at providing an affordable, dependable, and multi-powered system that will be appropriate for a wide range of applications, particularly in low-income nations such as Tanzania.

1.2 Statement of the Problem

Mortality and difficulties during childbirth have been an issue in the health sector worldwide; especially in Sub-Saharan Africa notably in Tanzania, as a result, more than 40% of children (neonates) die. According to the literature, neonatal fatalities account for 40% of all deaths in children who are under the age of five (MOHSW, 2015) as the chart demonstrates in Fig. 2. Most of the causes of this death can easily be predicted, controlled, and effectively eradicated if proper tools and strategies are put in place. It has also been noted by researchers that there are several existing initiatives to overcome these challenges that cause neonatal fatalities however most of them have not deployed emerging technologies innovatively to fit. They are largely the result of avoidable factors. Asphyxia was the top cause of newborn death in Tanzania in 2012 followed by prematurity, and sepsis (Afnan-Holmes *et al.,* 2015).

Over the last ten years, the Maternal Mortality Ratio (MMR) has been constant, and it is now predicted to be 578 per 100 000 live births. Tanzania has made significant success in lowering child mortality, however, with 32 per 1000 live births, infant mortality remains high accounting for 47% of the overall infant mortality rate of 68 per 1000 live births (MOHSW, 2015)

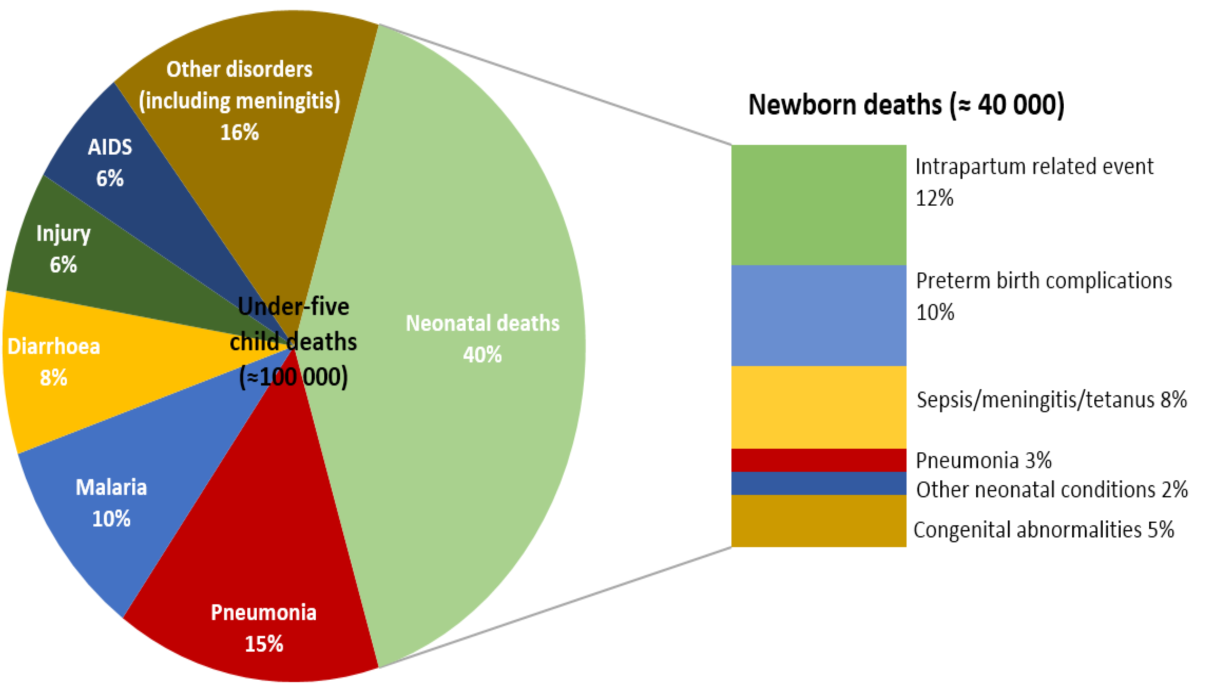


Figure 2: Under 5years Child Death Cause

Improper planning and inadequate support for babies with health difficulties have been cited as major contributors to this high fatality rate. According to Ministry and Healthy and Social welfare in Tanzania, there are two types of important issues observed in lowering maternal, neonatal, and morbidity and mortality in children:

(i) Health system factors: Poor health management at all levels, inadequate implementation of pro-poor policies, a lack of health infrastructure, limited access to quality health services, insufficient human resources, a shortage of skilled health providers, weak referral systems, low utilization of modern family planning services, a lack of equipment and supplies, and poor health management at all levels.

(ii) Non-health system factors: Inadequate community involvement and participation in health-care planning, implementation, monitoring, and evaluation, some social-cultural attitudes and practices, gender inequality, a weakened educational sector, and poor health-seeking behaviour are all factors.

Improved new born care leads to a higher rate of survival. The goal of this project is to create a design that ensures the safety of kids born with problems by offering efficient and effective care to aid their development.

1.3 Rationale of the Project

Mount Meru hospital is a referral hospital based in the Arusha region. Approximately 180 to 200 children are born in the hospital monthly. Newborn babies are less immune to infectious diseases and may face complications during and after delivery. The hospital has a neonatal unit to service pre-mature babies, sick babies within one month since the delivery period, underweight (less than 1 Kg), overweight (above 4 Kg), jaundice which is the yellow tint on the skin or whites of the eye, hypoxia as the absence of enough oxygen in the tissues to sustain bodily functions, hypothermia (low body temperature), and children born through surgery who cannot have mother's support during early days. Failure to combat these complications has been a leading cause of mortality rate for children under five years.

1.4 Project Objectives

1.4.1 Main Objective

To develop a low-cost IoT-based incubator to monitor and control infant vital parameters, support pre-term birth and other babies' complications that will lead to reducing the mortality rate for children in Tanzania.

1.4.2 Specific Objectives

The following precise objectives must be met to meet the project's goal:

(i) To collect requirements for designing and developing a low-cost IoT-based incubator for infants that will accommodate Tanzania's settings.

(ii) To develop the proposed low-cost IoT-based incubator

(iii) To implement and test the developed system

1.5 Project Questions

(i) What requirements are needed for designing and developing a low-cost IoT-based incubator for infants that will accommodate Tanzania's settings?

(ii) How would the proposed low-cost IoT-based incubator be designed?

(iii) How would the developed system be evaluated?

1.6 Significance of the Project

(i) To reduce hospital costs in buying equipment, especially in a low-income setting

(ii) To reduce the mortality rate in neonates due to asphyxia, hypothermia, and jaundice

(iii) Knowingly the impact of ICT and web technology in the health sector the system will integrate all neonates' data into one web page for current and future uses making it easier to manage and track the neonate's particulars.

1.7 Delineation of the Project

The objective of this project was to create a low-cost infant incubator in Tanzania that could be powered by both mains power and solar power or something similar. The device is designed for hospital use and focuses on reducing mortality rates and lowering purchasing costs in low-resource settings such as Tanzania and Sub-Saharan Africa. The project began with requirement analysis, followed by design, development and evaluation. This project assumes that all treatment centres have an internet connection that will enable the data to be sent to the cloud. Also, it assumes that all medical personnel have the skills and ability to use ICT devices along with operating the incubator.

CHAPTER TWO

LITERATURE REVIEW

2.1 Causes of Neonatal Deaths

In Tanzania specifically, the main causes of neonatal deaths are asphyxia which is the most common reason for newborn mortality, followed by complications from preterm births and infections due to sepsis and pneumonia (MOHSW, 2015).

2.1.1 Preterm Birth

According to literature, preterm birth or a premature birth occurs when a baby is born before the 37^{th} week of pregnancy contrasting to full-term delivery at around 40 weeks or 9 months. Sometimes preterm can be extremely early, that is before the 28 weeks who are less likely to survive; whereby early preterm is between 28-32 weeks and late preterm birth is between 34–36 weeks of gestation. One of the worst conditions is those premature infants are unable to keep their body temperature within the recommended range in comparison to fully developed children, who can regulate their body temperature. In addition, it has been noted that approximately 15 million, that is 1 in 10 babies have preterm birth every year and many babies who survive death face lifetime disabilities such as learning, visual, and hearing impairment. Furthermore, due to these statistics, approximately 1 million children die each year due to complications of preterm birth (WHO, 2006).

(i) Causes of Preterm Birth

According to Behrman and Butler (2007) multiple pregnancies, infections, and chronic conditions like diabetes and high blood pressure are all significant causes of premature birth; however, many times no cause is determined. In addition, early labour induction or cesarean delivery, whether for medical or non-medical reasons is responsible for the majority of preterm deliveries. It's also possible that a hereditary element is at play since preterm birth can occur for a variety of causes. Hence there is a need for further research into understanding the cause of preterm birth and the required mechanisms to be put in place to reduce and if possible eradicate the occurrence of preterm birth (Centers for Diseases Control and Prevention [CDC], 2020).

(ii) How to Prevent Preterm Birth

According to Shapiro-Mendoza *et al.* (2016), healthy pregnancy care increases the likelihood of a healthier pregnancy growth and delivery. A positive pregnancy experience will be assured by better health care before, between, and during pregnancies. As per World Health Organization (WHO), antenatal care guidelines include key interventions to help prevent preterm birth, such as:

(i) Counselling on nutrition and a healthy diet

(ii) The use of ultrasound to calculate gestational age and detect multiple pregnancies is one of the fetal measures.

(iii) Increased empowerment and enhanced access to contraceptives

2.1.2 Asphyxia

Asphyxia refers to a lack of oxygen and blood flow to the brain. It occurs as the baby gets less oxygen which results before, during, and immediately after birth. In this situation, the baby's brain and other organs do not receive enough oxygen and nutrition and this sometimes can happen without anyone being aware of it. Hence, the cells of the born baby fail to function effectively without oxygen and nutrition as the result the waste products (acids) build up and cause harm (Aslam *et al.*, 2014).

(i) Symptoms of Birth Asphyxia

- Acidosis (too much acid in the blood), meconium-stained amniotic fluid.
- Weak reflexes and no or extremely limited breathing.
- Skin that is bluish, grey, or lighter in hue than usual.
- Low heart rate and a lack of muscle tone are two symptoms that you should be aware of.

(ii) Treating of Birth Asphyxia

The treatment involves breathing support by a supply of enough oxygen to the baby till the condition is rectified. Babies with more severe asphyxia may require medical attention:

- Body cooling and medication to control pressure.

- Seizure treatment and kidney support.

2.1.3 Jaundice

Jaundice is defined as a yellowing of the skin, mucous membranes, and sclera due to the deposition of yellow-orange bile pigment called bilirubin (Abbas *et al.,* 2016). The breakdown of heme produces bilirubin. Differences in bilirubin production and clearance in newborns cause physiological hyperbilirubinemia, a spike in bilirubin levels that occurs in as many as 60% of all normal neonates in the first few days after delivery. Jaundice is a life-threatening disease as it can lead to biliary atresia (BA) and liver failure (Chee *et al.,* 2018).

Figure 3: Jaundice patient

The American Academy of Pediatrics issued guidelines on the management of hyperbilirubinemia in babies 35 weeks or more gestation in 2011 to assist clinicians in making decisions about when to initiate phototherapy. Newman *et al*. (2009) presented a method for using phototherapy and exchange transfusion in preterm neonates with a gestational age of fewer than 35 weeks.

(i) Phototherapy

The use of the electromagnetic spectrum or certain light wavelengths in the treatment of physical and mental illnesses is known as phototherapy (Maisels & McDonagh, 2008). People who are receiving this treatment are exposed to light sources, such as halogen lamps, sunlight, and light-emitting diodes as shown in Fig. 4. Blue light is used to treat neonates who have jaundice. The amount of light to be delivered must be considered in order to achieve optimal dosing. When exposed to blue light, bilirubin is broken down and transformed into water-soluble photoproducts that can bypass the hepatic conjugating machinery and be eliminated without further metabolic processing (Cabacungan *et al.,* 2020).

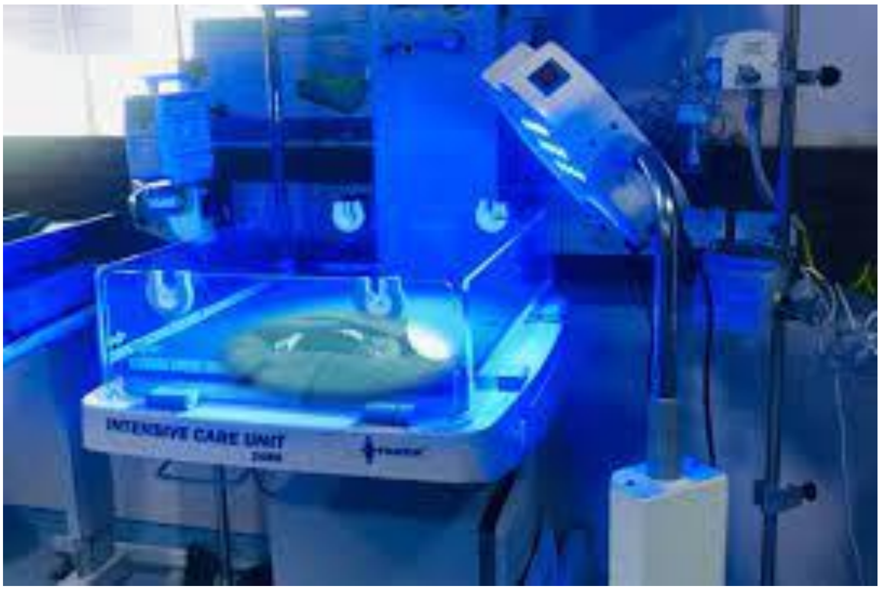


Figure 4: Phototherapy unit

According to different studies, different lights can be used to treat a certain type of disease as listed in Table 1.

Table 1: Types of phototherapy lights

Color	Treatment
Red	Energize
Orange	Spirit-lifting
Yellow	Toxin elimination is stimulated.
Green	Cooling, Relaxing. Reduces Inflammation
Blue	Peaceful effect
Violet	Promotes awareness, consciousness.
	Improves mental ability
UV Spectrum	Penetrating effect. High energy to kill diseased areas.

As far as Jaundice is involved, standard blue lights are the most efficient for neonatal phototherapy. Commercially available Light-Emitting Diode (LED) is widely used in this aspect. The Neo Blue LED systems use the best blue LED technology available. Blue LEDs emit blue light in the spectrum range between 450 and 470 nanometers wavelength. Because they do not emit light in the UV or infrared spectrum, they are the safest phototherapy devices available. Other types of phototherapy include halogen spotlights and fiber-optic phototherapy

Risks of Phototherapy

Maisels and McDonagh (2008), observed that premature babies in NICU are likely to have retinal damage. So eye protection continues to be the standard procedure during phototherapy.

2.1.4 Thermal Neutrality and Thermoregulation in Premature Infants

The term "thermal neutrality" refers to the scenario in which a person's body temperature is such that exposure to cold or heat does not cause an increase or decrease in the amount of heat they produce (Simbruner *et al.,* 2005). While the ability of the body to maintain a normal body temperature by balancing the heat produced by the body with the heat lost by the body is known as "thermoregulation" (Pereira *et al.*, 2016).

A preterm infant's thermal neutral environment is one in which the infant's metabolic rate is low and his core temperature is normal. According to Simbruner *et al*. (2005), preterm children should have a thermal environment that is comparable to that of their mothers while they are still in the womb. The premature child must all be nurtured in a setting where it generates relatively minimal metabolic heat to grow properly in which is highly affected by environmental factors thus as the ambient temperature drops and there is a cooling, the infant's metabolic rate increases and drops as the atmosphere are warm again.

(i) Hypothermia

One of the most important aspects of child mortality is hypothermia. Hypothermia is a condition in which the body loses more heat than it can hold, resulting in a drop in temperature. It is defined as a body temperature of less than 35.0°C (95.0°F) in individuals (Turk & pathology, 2010). The opposite of this is hyperthermia referring to a high body temperature of 98.6°F (37.0°C) or higher.

How Neonates Lose Heat

According to Cabacungan *et al*. (2020), neonates exchange heat with their surroundings via four channels as illustrated in Fig. 5:

(i) Evaporation: Heat loss from the skin and respiratory tracts owing to evaporation of water.

(ii) Conduction: Heat loss to cool the surrounding air.

(iii) Convection: To cool solid objects in direct physical touch, heat is lost.

(iv) Radiation: Heat loss to cool solid objects which are not in direct physical contact.

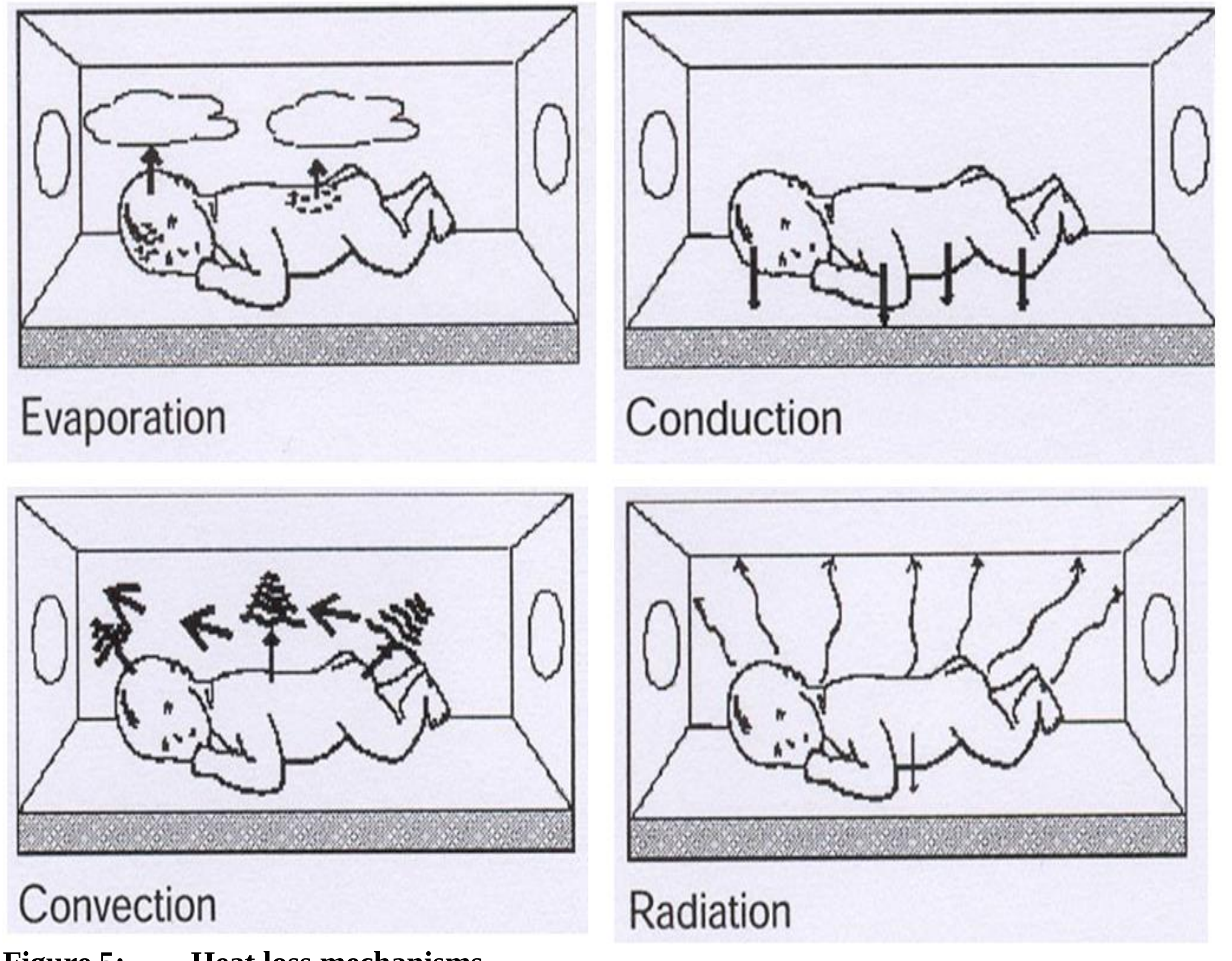


Figure 5: Heat loss mechanisms

2.1.5 Kangaroo Medical Care

In nature, mother comfort is essential for the child's development. This practice is known as KMC or Kangaroo Medical Care since it resembles the pouch of a kangaroo. It is a method of assisting preterm babies that involves wrapping them with a material such as a cloth that is close to their mother's skin as seen in Fig. 6. The mother can readily identify the baby's state, which aids in the baby's gain of warmth, calms and regulates their heartbeat, improves bonding, and aids in the establishment of excellent nursing practices and heart rate adjustment (WHO, 2003).

Figure 6: Kangaroo Medical Care

According to current World Health Organization (WHO) guidelines, kangaroo mother care should begin only after the infant has been stabilized in an incubator or warmer for 3-7 days. According to this new study, initiating kangaroo mother care as soon as possible after birth could save up to 150 000 more lives per year than the current norm (WHO, 2003).

2.2 Historical Trend of Modern Incubators

The development of the incubator by French Obstetrician Dr. Étienne Stéphane Tarnier in 1880 sparked a tremendous upsurge in public and professional interest in the possibility of lowering preterm infant mortality. Over the next 50 years, however, technological advancements came slowly and unevenly. The significance of the story lies less in the advancement of technology and more in the process through which the care of the baby is passed from mothers to obstetricians and then doctors. It also demonstrates how technological history goes beyond invention. The construction of a system to support the incubator was more important than its invention (Nicuawareness, 2021). Table 2 lists the innovations that paved the way for the establishment of the modern incubator.

Table 2: Historical trend of incubator

Year	Inventor	Invention
1891	Dr. Alexander Lyon	The Incubator was the first of its kind in the contemporary era.
1898		At the Trans Mississippi Exposition in Omaha, Nebraska, the first American Incubator Hospital was established.
1907	Pierre Constant Budin	The study Influence of Body Temperature on Infant Mortality was been released.
1932	Julius Hess	In his incubator patents, he developed a system for supplementing the incubator's oxygen supply.
1933	Blackfan and Yaglaw	A paper was released on the improved survival of newborn infants who were raised in a humidified atmosphere.

The realization that heat, humidity, and a constant supply of oxygen might improve the survival rates of sick babies meant that the hospital could effectively hospitalize the babies rather than send them home prompting the formation of special care units for infants. The units were initially exceedingly expensive, and there was no evidence of their effectiveness, therefore the hospital was hesitant to acquire such a modern product. Hospitals did not begin to construct Special Care Baby Units, the forerunners to current NICUs, until after World War II (Nicuawareness, 2021).

2.3 Various Kinds of Warming Devices in Neonatal Intensive Care Units

In the NICU, there are various methods of warming. The housing configuration, size, and control method are the key differences in the designs. The kinds' key feature is that they create a warm environment where temperature, relative humidity, and oxygen concentration can all be easily managed (Hey & Mount, 1967). Based on size housing and control methods they can be categorized as follows (Verywell family, 2021):

(i) A fresh air filtering system in closed box incubators reduces the risk of infection by preventing moisture loss from the air.

(ii) Double-walled incubators have two walls that can further prevent heat and air moisture loss.

(iii) Armstrong incubators, sometimes known as open box incubators, give radiant heat beneath the baby while remaining open to the air, allowing for easy access.

(iv) Portable incubators often referred to as transport incubators, are used to carry the infant from one area of the hospital to another.

(v) Servo-control incubators are configured to automatically regulate temperature and humidity levels based on the baby's skin sensors.

In the neonatal critical care unit, two types of warming equipment are currently in use (Lyon *et al.*, 1997; Meyer *et al.*, 2001).

2.3.1 A Radiant Warmer

As displayed in Fig. 7, the heating source is located above the open bed in this design. It allows for direct contact with the newborn while also providing radiation warmth. The infant is more susceptible to illness as a result of a large amount of humidity loss produced. Additionally, the child loses a significant amount of heat due to convection and evaporation (Meyer *et al.,* 2001).

Figure 7: Radiant warmer (Weithoner, 2022)

2.3.2 An Infant Incubator

It is a closed box structured unit as displayed in Fig. 8. Most incubators utilize convection heating, which decreases the risk of infection and prevents moisture loss from the air. Its crucial purpose is to preserve a baby at 37°C the core temperature. Because of the limitations of radiant warmers, new-borns must eventually be transferred to incubators (Lyon *et al.,* 1997). The baby is protected from noise, dust, illness, and excessive handling by the incubator chamber, which provides a clean atmosphere.

Figure 8: Infant Incubator (Weithoner, 2022)

2.4 Incubator Working Principle

Figure 9 shows the main basic components of an incubator which include sensors and condition-adjustment systems, which are necessary for keeping new born at the right temperature. It features unique lighting to treat newborn jaundice, which is frequent in infants, and it can manage air humidity to keep the skin healthy. It also features a control panel and an alert mechanism that will notify medical personnel if the baby is in a life-threatening situation.
Incubator main parts:

(i) Heater: The room air is heated to the desired temperature as it passes over the heater.

(ii) Humidifier: The humidifier humidifies the heated air to the appropriate humidity level.

(iii) Front Panel: This is used to communicate with the machine to perform the required action.

The temperature of the incubator can be controlled using the following controls modes:

(i) Skin servo

(ii) Air servo

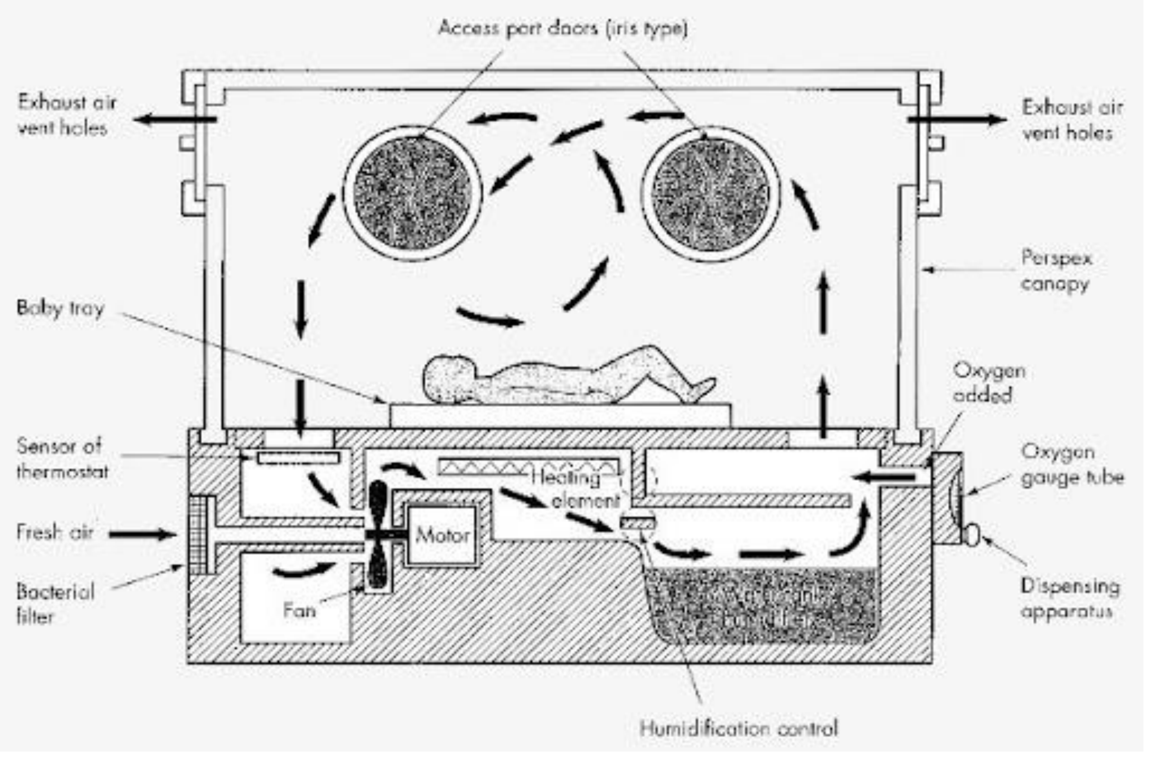


Figure 9: **Incubator parts (Weithoner, 2022)**

Table 3 depicts the incubator's typical regulated variables.

Table 3: **Typical maintained values**

Parameter	Typical range
The temperature of the air	32°C to 38°C
The temperature of a baby's skin	34°C to 36°C
Total gas consumption	35 l/min
Relative humidity	50-100%

2.5 Related Works

According to several works of literature, several studies have been achieved to support newborn babies born at preterm birth. These studies include the study done by Singla *et al*. (2015) who devised a microcontroller-based temperature and humidity control in the infant incubator. The prototype involved a DHT sensor, an Arduino, and a heater to control the temperature. The heater switched based on the measured surrounding temperature. The other study was done by Shabeeb *et al*. (2020) and Sony *et al*. (2021) devised an IoT-based remote monitoring system for a premature infant's incubator. It is similar to Singla's differs as it sends data to Things Speak through an ESP8266. Sony and his colleagues integrated a dipper wetness sensor in their design and biosensors. The data collected were relayed into the Blynk app over Wi-Fi. However, the system did not express any facts on power management and other features like phototherapy.

Srikanth *et al*. (2020) developed an IoT and GSM-based patient health monitoring system. Since people's lives have been influenced by modern lifestyles in a variety of ways, hence, majority of people do not have time to see doctors or visit a hospital. Hence they developed an IoT and GSM-based patient health monitoring system. The developed system included a series of sensors used to measure biological variables such as temperature, blood pressure, and muscular activity. Based on the data evaluated, the measured data were transferred through GSM to the caretaker or doctor. The system functions as a self-diagnostic device that helps people live better lives through continuous sensing, disease prediction, and immediate response. However, unlike Wi-Fi, GSM technology does not support real-time data streaming. As a result, Fahmi *et al.* (2020) created a smart incubator based on the Internet of Things that listens to the infant. Because babies can't communicate themselves, it's impossible to know what they're going through or what they desire. A baby's voice can convey a lot of information, such as sickness, hunger, and so on. The design included biosensors, environmental sensors, and a speech recording unit. Things speak acquired the measured data via Wi-Fi. The baby voice was classified using the spectrum analysis in the frequency domain approach. A baby's condition was anticipated based on the analysis. However, the system lacked visual streaming, which would have allowed for a more precise prediction of the situation.

Jabbar *et al.* (2019) created an IoT-BBMS (Internet of Things-Based Baby Monitoring System for Smart Cradle) as a more advanced technique. The number of working moms has risen dramatically, posing a significant barrier to baby care for many families daily. The microphone, video camera, DHT sensor, and motor were the main components of the designed system. The design had a baby cradle that would automatically swing using a motor when the baby cried. The parent or guardian could view the infant's environment through an IP camera. The NodeMCU was attached and programmed to collect data from the sensors and post it to the AdaFruit MQTT service through Wi-Fi. However, human involvement in child care, on the other hand, is critical for growth.

Mandke *et al*. (2018) and Nivetha and Kumar (2020) designed and developed an IoT-based baby healthcare monitoring system. The designed system used an MSP430 microprocessor connected with several sensors such as; a temperature and humidity sensor, a heartbeat sensor, a cry sensor, and a humidity sensor. The cry sensor is a voice recording module that records the baby's voice. The overall device data ware sent to the cloud for further diagnosis. A similar strategy was done by Mandke *et al.* (2018) for baby care. It differs from the previous model in that it incorporates a motion sensor that detects the baby's movement and reports the data to the parent, guardian, or doctor. Both systems, on the other hand, have flows since they don't express the fact of cost reduction and efficiency

Cabacungan *et al*. (2020) created an electronic sensor and monitoring system for the non-invasive treatment of neonatal jaundice with a low-cost phototherapy light system. They emerged with a design that featured a DHT22 and a photoresistor to detect light intensity, all of which connected to an Arduino, which relayed sensor data to a Raspberry Pi with a camera attached. All of the measured data were analysed and visualized using Things speak. The LEDs replaced the traditional bulb used earlier as they performed 90% more efficiently than the bulbs. Similarly, Mittal *et al.* (2015) conceived and built an Infant incubator with multiple parameter control. The parameters monitored include; temperature, humidity, oxygen, and light. Compared to compact fluorescent lamps (CFLs) or halogen light sources, a light-emitting diode (LED) was found to be more effective as a phototherapy light source. Both designs, however, are unable to accurately assess the level of yellowish in the baby's skin, necessitating manual phototherapy adjustments.

Heat control is crucial in an infant incubator thus an advanced portable preterm baby incubator was created (Shaib *et al.*, 2017). Similar to previous related works in which vital parameters are monitored and controlled. The system provided an efficient method of heat control. They measured the parameter with infrared sensors. Surprisingly, the devised method included gel packs, which stored and changed heat by conduction to maintain the appropriate newborn temperature. The heater warmed up the gel pack. The device was lightweight, inexpensive, and high heat maintenance efficient. Tran *et al*. (2014) designed Low-Cost Multifunctional Infant Incubator. The sensor network and monitoring appeared to be similar to the others, although they differed primarily in the case of heat regulation. Through investigating thermally insulating materials and conducting tests to find the ideal configuration for the lowest heat transfer loss, they produced a thermodynamically improved low-cost incubator with insulation capabilities and high heat efficiency. The insulation lowers the operating costs and fits in low-resource situations. However, further research is needed for both approaches to discover the best material and arrangement.

Because distance appears to be a problem for Zigbee, Wi-Fi, and Bluetooth; Sendra *et al*. (2018), developed a Smart Infant Incubator Based on LoRa Networks. The system incorporated DHT22 for temperature and humidity and weight sensors that tracked the infant in the unit. Each incubator was linked to a central network using Long Range Networks (LoRa), which allowed medical data stored in a database. A Near Field Communication (NFC) interface was included in the system, allowing clinicians to identify, check the patient's progress on a smart device, and add new data. However, although LoRa extends a few hundreds of kilometres, it is not without distance flaws.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This Chapter explains the methodologies, techniques, and materials used to bring about this study. It describes the case study area, data collection methods, system requirements and development.

3.2 Case Study

In the current project, Tanzania was selected to be the study area and specifically, it was carried out at Mount Meru Hospital, which is a referral hospital based in the Arusha region and the neighbourhoods. For the reason that it is a referral hospital, it receives and treats predominantly complications that are difficult to treat in other hospitals. It was advantageous since I did my internship there, it has a significant number of professional doctors and resources, and it receives and treats a huge number of patients from Arusha and the outlying neighbourhoods.

3.3 Data Collection

It entails gathering data that can be used to reveal the need for the proposed system, explaining the evidence that demonstrates the existence of a problem in the current system, and assisting in obtaining answers to the specified research questions, testing hypotheses, and evaluating the results. This project's data was divided into two categories: Original data and secondary data.

3.3.1 Primary Data Collection

These are unknown data or freshly collected data in which five different hospitals were consulted; Mount Meru, KCMC, Muhimbili, Bugando and Tanga referral. Methods employed were for the reason of easy access to hospital facilities and cheap in terms of transit cost and limited time. Several approaches were adopted as follows:

(i) Consultation or Interview

The interviews conducted were particularly for the head of departments and other medical personnel in the exact subsection and particularly Biomedical Engineers.

The technical part interview mainly involved technicians and Biomedical students, since the nature of the project is product or the prototype. Among the hospitals I visited, two Biomed Engineers from Mt. Meru and five Biomed Engineers from KCMC where interviewed. Knowingly currently Biomedical Engineering course is offered in some of the institutions in the country I visited Arusha Technical College and interviewed a class of nearly 40 students of bachelor degree. Based on their knowledge they gathered in their studies and the one from practical training the following aspects were observed which looks similar to the ones I gathered from the professional ones.

Qnustion 1: Why Do Many Medical Equipment Get Damped and Not Get Repaired

- Unavailability of the spare parts.
- Complex procedure to follow when one wants to procure new spare parts and time it takes for one to have them on hands.
- Contractual agreement between the seller and the buyer. Other sellers do not allow their device to be repaired apart from them only otherwise the contract is void.
- Lack of knowledge and less training especially on the new product knowingly the technology if daily changing.

Other questions asked from the Administrative and medical of about 10 in total and their response in general are as follows:

Question 2: Why Are there Few Incubators in Most of the Hospitals

- Lack of budget for most of the hospital.
- Procurement procedures and poor policy.
- Bureaucracy among many of the workers.

(ii) Observation and Questionnaire

The observation was conducted on both medical personnel on how they handle the babies and biomedical engineers on how to operate, repair and maintain the device. The questionnaire mainly focused on obtaining the data on how easy, reliable, and effective are the devices, what other approaches they use, the statistics of the preterm, and the suppliers they use to purchase the devices.

(iii) Workshop and Training

By repairing fault Incubators and other medical tools mainly used in a pediatric department with the help of professional biomedical engineers helped to understand how the devices well and capture the required requirement.

3.3.2 Secondary Data

Reports, books, articles, the internet, various publications, etc. were used to capture significant information used in the development of this project. The documentations were analyzed to identify the gaps, recommendations and solutions done by other colleagues.

3.4 System Development Model

Different system development life cycle (SDLC) methodologies can be used to develop the system (Rastogi & Technologies, 2015). Since the system is not new and the requirements are well known, the agile model in Fig. 11 which is an advanced approach to the waterfall model in Fig. 10 is adopted to develop this system.

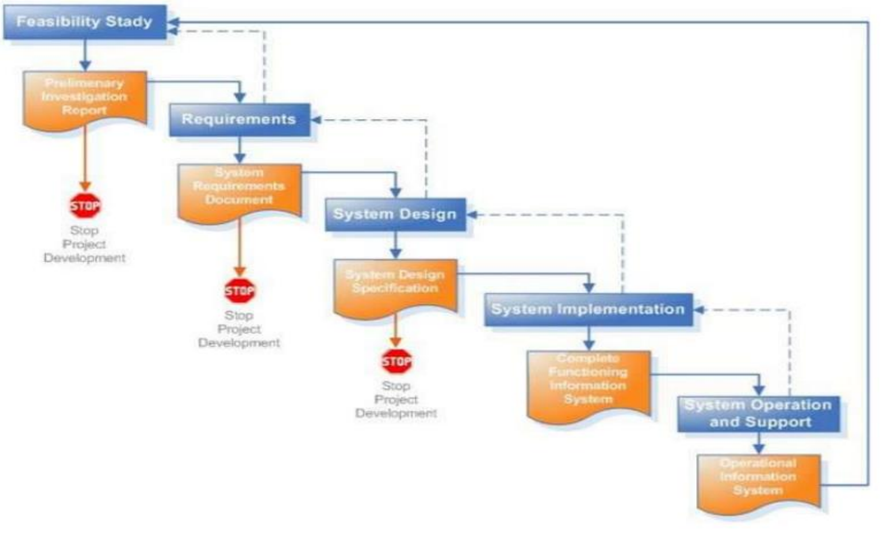


Figure 10: Waterfall Model (McCormick, 2012)

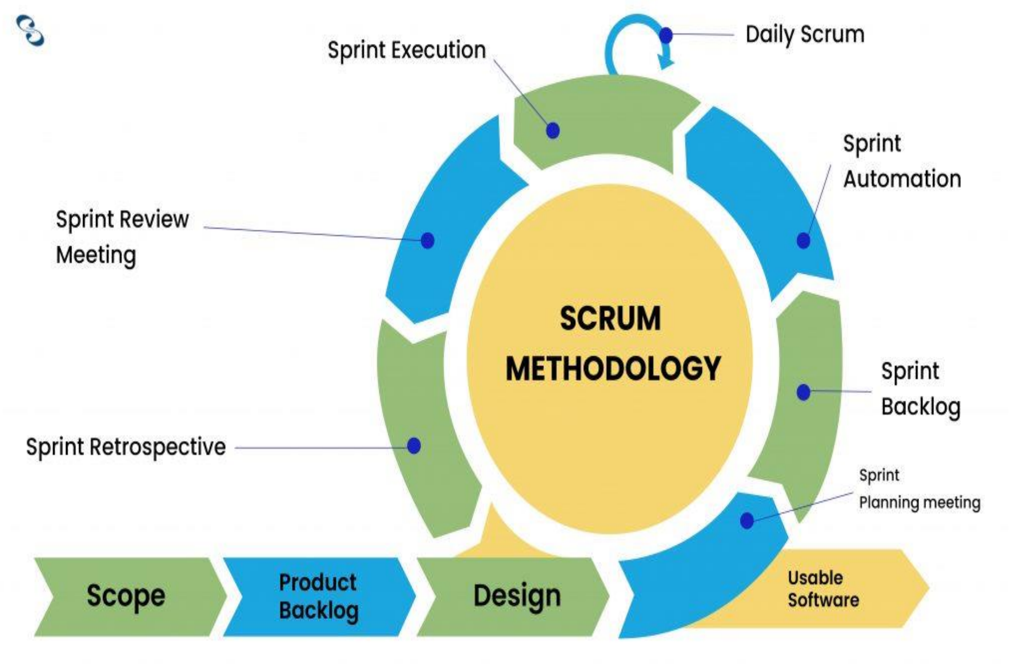


Figure 11: Scrum Agile Model (McCormick, 2012)

The selected model has the following advantages over the waterfall model or the others:

(i) Scrum can help teams complete project deliverables quickly and efficiently.

(ii) Scrum ensures effective use of time and money.

(iii) Large projects are divided into easily manageable sprints.

(iv) Developments are coded and tested during the sprint review.

(v) Works well for fast-moving development projects.

With the scrum agile model, system development and testing processes can be conducted in parallel hence speeding up the project to meet the required deliverable.

3.5 Hardware and Software Requirements

Because the project entails hardware and software integration, various tools were employed for the incubator and web parts. Because of its reliability, user-friendliness, interoperability with a wide range of apps, and security, the Windows 10 operating system was utilized in both approaches.

3.5.1 Software Tools for Incubator Unit

Proteus was mainly used for circuit designing and simulation along with PCB designing and Arduino IDE was used for ESP programming in which C++ language was used. The choice was mainly due to availability as both of them are free, compatible, and rich in several features.

3.5.2 Software Tools for Web

Front End Programming Languages

The interfaces of a website or software program that are presented to users are referred to as the front end in programming technology. Bootstrap is a CSS framework that focuses on responsive, mobile-first front-end development. It includes templates for typography, tables, forms, modals, and other elements that make it easier to create a website rapidly. The programming languages used in Bootstrap are as follows:

- **Hypertext Markup Language)**

The Hypertext Markup Language (HTML) is a standard language that semantically explains the structure of a web page and originally included cues for the web page's form. It can be embedded with JavaScript and CSS, which define the content's behaviour and layout, respectively. Because of this, HTLM5 was chosen.

- **JavaScript**

JavaScript or JS is a high-level multi-paradigm language that supports object-oriented, functional, and imperative programming styles. It is among the core technologies alongside CSS and HTML of WWW. It is mainly used to make the web page dynamic and interactive for a better user experience

- **Cascading Style Sheets**

The style of the frontend interfaces in this project was created using Cascading Style Sheets (CSS). It is a style sheet language that may be inserted in HTML and describes the layout, colors, and fonts of a document. It is considered one of the most important languages in World Wide Web technology.

Backend Programming Languages

- **CodeIgniter**

CodeIgniter is an open-source software web framework based on the popular model–view–controller (MVC) development model for use in structuring dynamic websites with PHP programming language. It connects to the database and also provides means of uploading and managing files.

- **XAMPP Server**

The XAMPP is a cross-platform web server solution stack that is free and open-source that is mostly used as a local web server for SQL databases, PHP, and other applications. It mostly comprises the Apache web server, Maria DB database, and interpreters for PHP and Perl scripts (Wikipedia). The developed site was hosted locally using the XAMPP server under this system.

- **MySQL**

The MySQL is an open-source relational database management system with a structured query language (RDBMS). Its primary function is data storage and manipulation, with data structured into one or more data tables and data types connected. The MySQL makes it possible to store information on the neonate, including the parameters that are being measured.

3.5.3 Hardware Description Tools Used

(i) ESP 32

Figure 12 is the ESP32-WROOM which is regarded as a powerful, generic board that includes the ESP32-D0WDQ6 microcontroller chip, which features two CPU cores that may be managed independently. The clock frequency can be adjusted between 80 and 240 MHz, and the board is equipped with Wi-Fi, Bluetooth, and Bluetooth LE, allowing for a wide range of applications, from simple to complex, especially those involving communication, such as direct internet access via Wi-Fi and phone connectivity via Bluetooth. The board is Arduino compatible, making it simple to program and use, and its extensive collection of peripherals, including SPI, UART, I2C, I2S, and others, ensures its suitability for a wide range of applications (EspressifSystems, 2018).

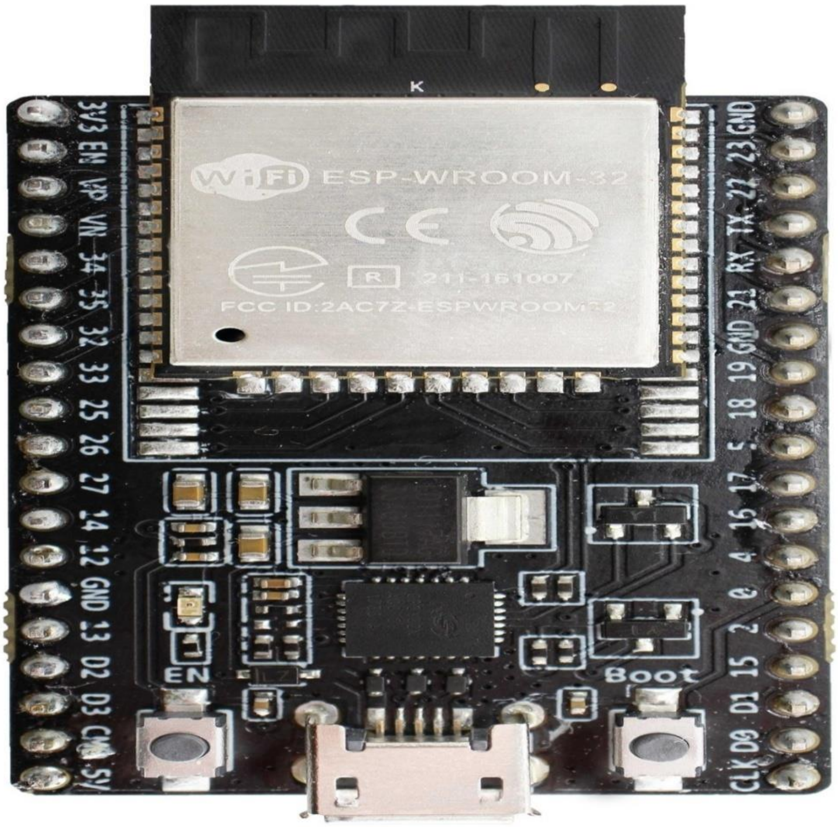


Figure 12: ESP32

(ii) Metal Head Thermistor - 3950 NTC

It's a waterproof 10 K ohms negative temperature coefficient resistor with stainless steel covering as seen in Fig. 13, that measures temperatures from -20 to 105°C. The thermistor resistance decreases as the temperature rises, with an accuracy of -/+ 1 percent of the measured temperature. The variation in sensor resistance correlates to the temperature of the baby's skin.

Figure 13: Thermistor

(iii) Solenoid Valve

Figure 14 is an electrical actuator that opens when voltage is provided, allowing one-way passage of gas, in this case, oxygen. The valve's main purpose is to allow oxygen flow to control the air quality in the neonatal room; when the air quality falls below a certain threshold, the valve opens to let oxygen flow into the room.

Figure 14: Solenoid Valve

(iv) Heater

Figure 15 is a heater mainly used for warming its adjacent by converting electrical to heat energy. The air present in the room of a neonate should be regulated thus when the temperature falls below the normal range, the heater will be activated to sustain the optimal level temperature required through the heat radiation through the airflow.

Figure 15: Heater

(v) Heart Rate and SPO2 Sensor

The MAX30102 is an LED Reflective Solution-based Pulse Oximeter and Heart-Rate Monitor. The internal photodetector, LEDs, optical elements, and low-noise electronics with ambient light rejection are all part of the package. As illustrated in Fig. 16, the gadget is connected through I2C and has seven functional pins. This sensor's principal purpose is to record the electrical activity of the babies' hearts (pulse rate) as well as blood oxygen saturation (SPO2)

Figure 16: MAX 30102

(vi) Temperature and Humidity Sensor

The DHT22 Temperature and Moisture sensor is used to measure the changes in the ambient humidity and temperature in its adjacent environment. The sensor is packaged with four pins as seen in Fig. 17. The sensing elements are which are a thermistor for temperature and a capacitive transducer for humidity are connected with an 8-bit single-chip computer and output a digital signal that is single-bus data interface communication with the microcontroller unit in which both temperature and moisture content are sent. The sensor is used to measure the surrounding temperature and humidity of the neonate room (Liu, 2013).

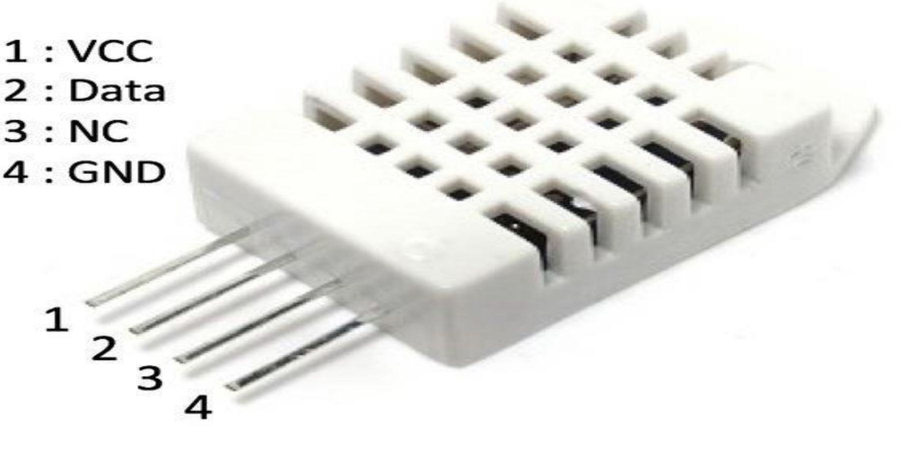


Figure 17: DHT22

(vii) **Switching and Isolation**

A relay in Fig. 18 is an electrically operated switch. When voltage is given to it, it alters its position electromechanically. This provides isolation by periodically isolating a segment of a circuit from the rest of the electrical power supply. The switching voltage, which in our case is 5V, and the power consumption of the load, which determines the relay's amperage, were used to select the relay.

Figure 18: Relay

(viii) **UltraViolet Light Sensor**

The UV/GY 6070 is a sophisticated sensor with spectral sensitivity to cover the UV spectrum sensing used for UV light sensors that operate from 2.7V to 5V. The sensor is 5 pins long and uses an I2C communication interface with the MCU, as shown in Fig. 19. The main goal is to determine light intensity using phototherapy dosage as a guide. The detected light intensity is supplied to the controller for processing.

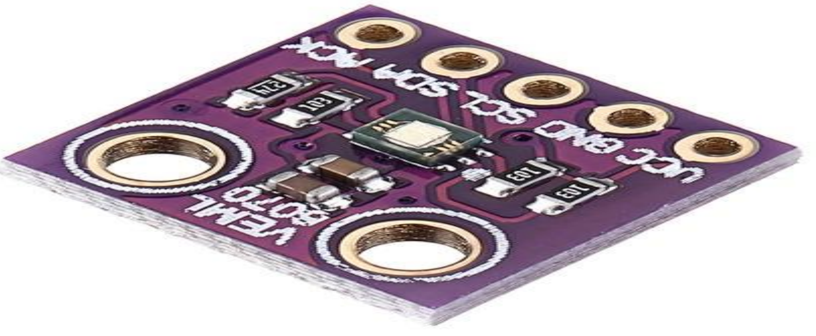


Figure 19: UV/GY 6070

(ix) **Display**

Thin Film Transistor (TFT) displays are active graphical colour matrix liquid crystal displays with a touch panel. The module has a higher resolution with a 240 × 320-pixel area, which is ideal for visualization as seen in Fig. 20. The gadget is connected to an Arduino Uno, which receives data from the ESP 32 through an I2C connection and displays all of the measured values, as well as the settings and alert status.

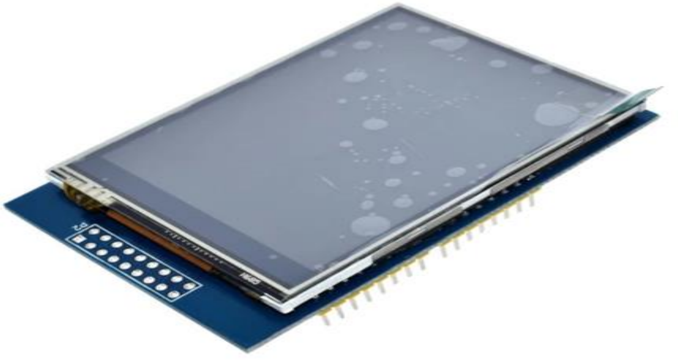


Figure 20: TFT display

(x) Air Quality Sensor

In the neonates' chamber, the MQ 135 sensor is utilized to detect carbon dioxide levels in parts per million. The sensor is powered by 5V and has four pins, as shown in Fig. 21. The sensor's analog pin is connected to the microcontroller unit (ESP 32), and the value of air quality may be computed and controlled using the ADC. When PPMs are between 150 and 350, air quality is considered normal, and oxygen is added to the unit.

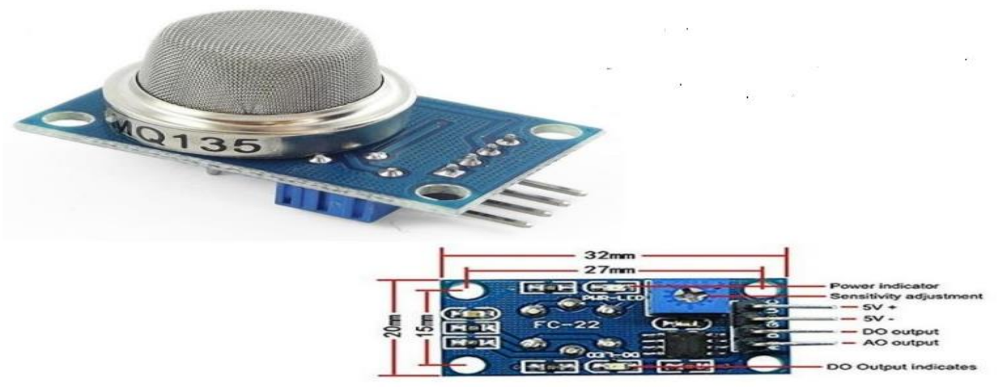


Figure 21: MQ135

(xi) Blue Light Source

Blue LEDs as shown in Fig. 22 were employed as a light source for the treatment of jaundice. Other light sources, such as halogen lamps and sunlight, can also be used to cure this medical condition, but LEDs are more successful. Blue light is used to treat newborns that have developed jaundice and to ensure effective dosing the intensity of light to be provided is considered.

Figure 22: Blue LEDs

(xii) SIM800L

The is a four-band GSM/GPRS module that operates between 3.4 and 4.4V and has GSM850MHz, DCS1800MHz, PCS1900MHz, and EGSM900MHz as working frequencies (SIMCom Wireless Solution Co., 2013). Figure 23 shows the device which is equipped with GSM wireless technology, which provides worldwide coverage. The UART DCS1800 MHz, PCS1900 MHz communication is used to connect the device to the MCU. Once a critical condition is detected, an SMS will be sent to medical personnel.

Figure 23: SIM800L

(xiii) Warning Device

A buzzer in Fig. 24 is a piezoelectric passive or active device that produces a sound of approximately 2300 Hz once the voltage is applied to it ranging from 1-5V. The main purpose of it is to notify the medical personnel when the neonate is in critical condition.

Figure 24: Buzzer

(xiv) Fan

A fan in Fig. 25 was used for cooling the unit and airflow. At approximately 3200RPM, the fan sucks in fresh air from the surroundings and circulates it inside the unit. It is also necessary for cooling when the temperature is above the setting.

Figure 25: Fan

(xv) Real-Time Clock

DS3231 in Fig. 36 is an accurate clock that maintains hours, minutes, seconds, days, months and years. It interfaces with the MCU via I2C and can be operated in 12/24 hours' mode. The main function

Figure 26: Ds3231 RTC Module

(xvi) Humidifier

As shown in Fig. 27 a 113 kHz Ultrasonic humidifier with PCB board is the best choice mainly because of its reduced power consumption and can produce humid air that is enough to humidify the surrounding. It uses ultrasonic waves at 113 kHz to heat and evaporate the water molecules.

Figure 27: Ultrasonic humidifier

3.5.4 Justification of Using the selected Software and Hardware

(i) Hardware selection

The main hardware component in this project is the microcontroller used that differentiates from other existing ones.

ESP 32

The ESP 32 was selected instead of Arduino or any other mainly because of the following reasons:

- The clock frequency can be adjusted between 80 and 240 MHz compared to 16 MHz of that Arduino Uno.
- The board is equipped with Wi-Fi and Bluetooth.
- It has an extensive collection of peripherals, including SPI, UART, I2C, I2S as communication protocols.
- Enough pins for the application.
- Large memory size (SRAM, flash memory and EEPROM) compared to that of Arduino.

TFT Display

The TFT display was used and not generic LCD like 20x4 or 16x2 mainly because it is big hence the quality of the image is improved also it can display graphical images.

Ultrasonic Humidifier

On the other hand Ultrasonic humidifier was preferred mainly because it uses less power, it can generate humid air faster compared to the heating water using a heater to get moist air. The sensor selection was mainly based on sensitivity, availability, reliability and cost and all of these factors were considered during the choice. Power consumption of individual components was also considered for instance the heater selected is of 40W DC and it was observed to perform best.

(ii) Software selection

Proteus 8.9

Proteus 8.9 or of above version was selected in this project despite other alike CAD tools available in the market like EasyEDA, Multisim, KiCAD and others mainly because of the following:

- It is easy to use and locally available among many users.
- Large supporting community
- Standalone desktop application compared to EasyEDA that is browser supported.
- Enrich with number of libraries and components that enhance perfect circuit design and simulation.
- It supports multiple layers PCB design and it has a trace routing algorithm for the PCB designing.

3.6 System Design and Specification

3.6.1 Block and Circuit Diagram

As illustrated in Fig. 28, the system comprises several input devices (sensors) and output devices, all of which are connected to an ESP32 microcontroller unit. The monitoring is accomplished as each sensor measures and transmits the associated parameter to the MCU, which is then processed. When any measured parameter deviates from the predetermined value, the MCU activates the relays to restore the state to normal. Any critical state triggers an alert, which sends a text message to medical personnel. Through the web application, the entire device may be monitored and operated remotely.

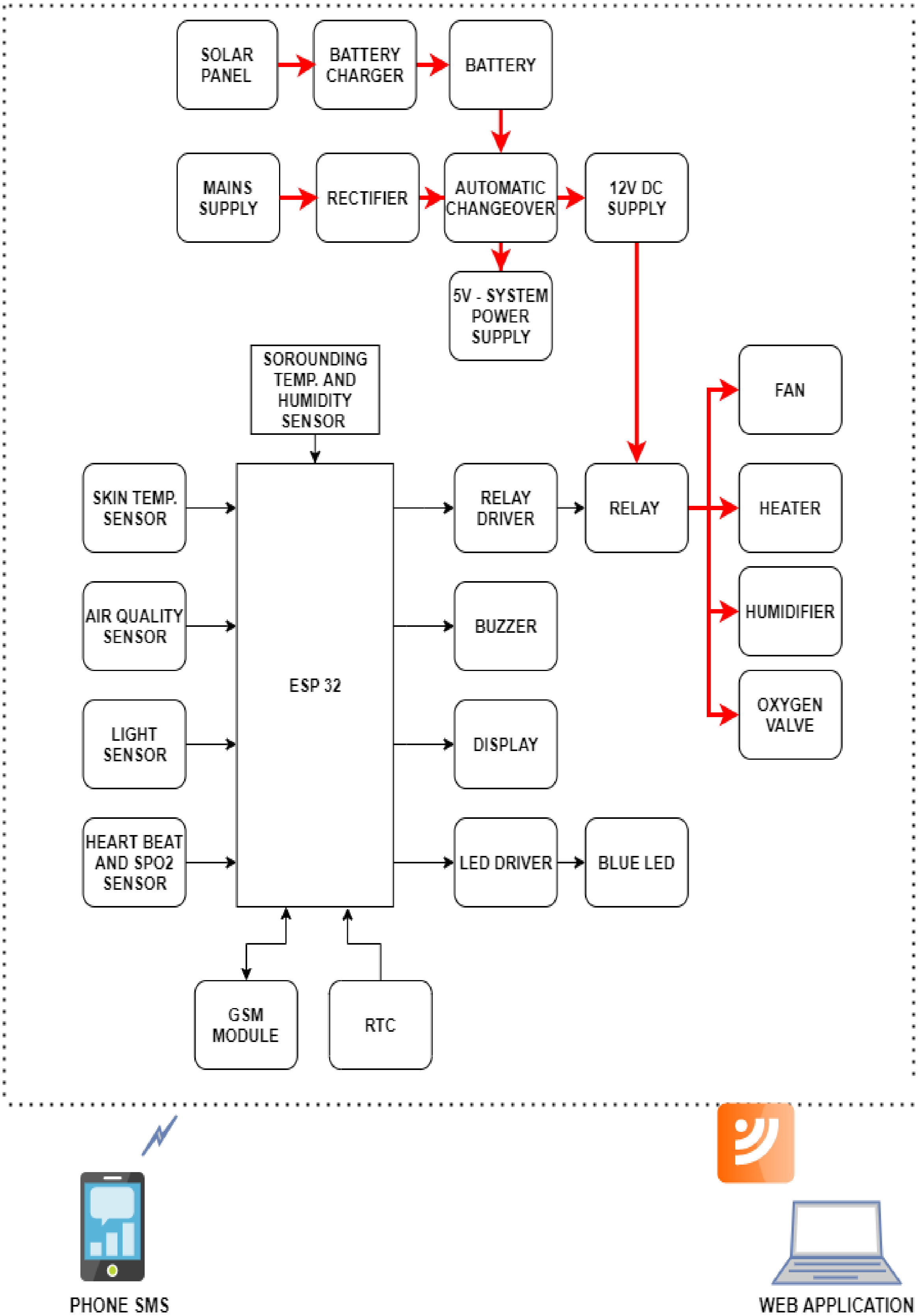


Figure 28: Block Diagram of the Developed System

3.6.2 Functional Units

The constructed system was divided into five functional units: sensing, processing, actuating and alerting units, as well as a web application.

(i) Sensing Unit

It comprises DHT 22, thermistor, MAX30102, UV/GY 6070 that are responsible computation of the neonate's parameter. The measured parameters are surrounding temperature and humidity, baby’s skin temperature, heartbeats, and blood saturation along with UV light measurement respectively. It is a crucial part of the system as it provides feedback on the baby's status to the controller for monitoring. MAX30102 and UV/GY 6070 utilize an I2C interface, DHT22 utilizes a single bus data interface and for the case of thermistor it uses ADC as they interfaced to the microcontroller unit.

(ii) Processing Unit

An ESP32-WROOM is a powerful board that includes the ESP32-D0WDQ6 microcontroller chip, which has two CPUs running at 80-240 MHz and 3.3V. The board is connected to the sensors as indicated in Fig. 34, receiving and analyzing sensor values for monitoring and control. If any parameter deviates from the threshold value, the control mechanism is activated to compensate for the situation. Because the board is Wi-Fi enabled, data is sent to the cloud over the internet, allowing for remote monitoring and control.

(iii) Actuating Unit

The oxygen valve, fan, heater, and phototherapy unit are all controlled by the MCU and are turned on and off via relays. Regarding the measured parameter from the sensors, air quality, chilling and circulating the air, warming the surrounding, and treating jaundice can all be managed.

(iv) Display and Alerting Unit

The major purpose of this device is to provide a visual display and to inform the user of the neonate's current condition. The TFT display, which is a wide-screen color matrix display, is used to show the user information on the neonate's vital measured parameters like temperature, humidity, heart rate, and blood oxygen saturation. When a neonate is in critical condition, a buzzing sound with a frequency of around 2300 Hz is produced by a buzzer, and an SMS is sent to medical personnel for further action.

(v) Power Supply

The system can be powered by both mains or any DC (12V) alternative supply like solar and alike. The mains power is stepped down, rectified and filtered then input into the changeover switch. Once mains power is off the system switches to DC alternative supply.

(vi) Web Application

The operators can handle this collection of data and offer analytical conclusions based on the data in the web database, which is a database application meant to be controlled and accessible via the internet. This website will serve as a central hub for all neonatal data, both current and prospective. Based on the data collected and maintained in the database generated on this website, the physician will be able to make an informed conclusion.

3.6.3 Initial Conditions and Parameter Values

The neonate's early conditions were chosen to be the same as those found in his surroundings. The ambient temperature is set to 29°C, which is the same temperature as the incubator's room temperature. Initially, the temperature of the incubator air space fluctuated between 26°C and 29°C. The temperature of the mattress was initially between 24°C and 27°C. The incubator walls were heated to a temperature ranging from 25°C to 27°C at first. The newborn's core temperature was 36°C, which was lower than the intrauterine temperature of 38°C. Initially, the temperature of the infant's skin varied between 33°C and 35°C (Thomas & Burr, 1999). The machine determines how to monitor and control the skin and environment temperature based on this initial setting.

3.6.4 Air Control Versus Skin Control

The fixed temperature is first found in skin control. When the detected temperature of the baby's skin falls below the specified temperature, the heater is activated, allowing hot air to flow into the incubator. The flow of hot air into the incubator was halted when the skin perceived temperature equalled the set temperature, that is, when the temperature difference between the set and detected temperatures was zero. For at least a few seconds, the hot air flow has been turned off. The maintained temperature in skin control mode is the baby's skin temperature, which is based on the reference temperature. In air control, the same process was utilized, but the fixed temperature was as atmosphere temperature. The difference between the fixed air temperature and the detected air temperature determines the rate of hot airflow.

3.6.5 System Inputs and Outputs Devices

Input devices send the signal to the MCU, whilst output devices receive the command or signal from the controller. As shown in Fig. 28, the arrows distinguish this. Tables 4 and 5 list input and output devices, respectively.

Table 4: Input Devices

Device Name	Function
DHT 22	Measures air temperature and humidity in the incubator
Thermistor	Measures infants skin temperature
MAX 30102	Pulse Oximeter and Heart-Rate Monitor
UV/GY 6070	Light intensity

Table 5: Output Devices

Device name	Function
Heater	Provides hot airflow into the incubator
Fan	Cooling and air circulation
Oxygen valve	Air quality compensation
Humidifier	Provides humid air in the incubator
LCD and Buzzer	Information display and alert

3.6.6 Flow Chart

As depicted in Fig. 29, a flowchart depicts the series of actions that the designed system does in sequential order. It depicts a method or process for obtaining results.

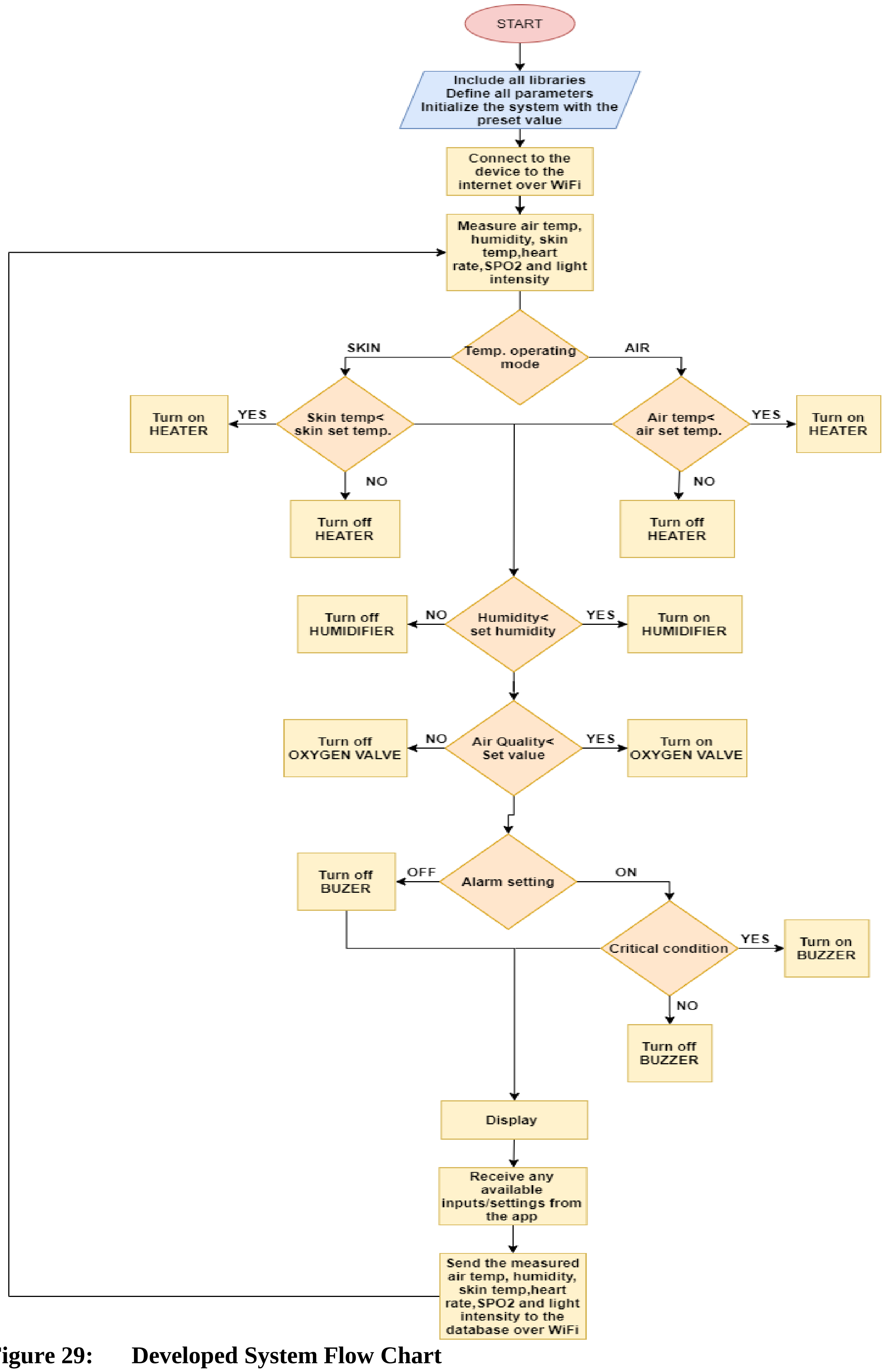


Figure 29: Developed System Flow Chart

3.7 Data Flow Diagram

The DFD visually represents the functions, or processes, that capture, manipulate, store, and distribute data between a system and its environment, as well as between system components. Because of the visual representation, it is a useful communication tool between the user and the system designer. The DFD enables the system's logical information flow, as well as the determination of physical system construction needs, notation simplicity, and the definition of manual and automated system requirements.

3.7.1 Context Diagram

A context diagram, also known as a level 0 data-flow diagram, is created to define and illustrate the limits of the software system as shown in Fig. 30. It controls the flow of information between the system and external entities. The entire software system is exhibited in a single procedure.

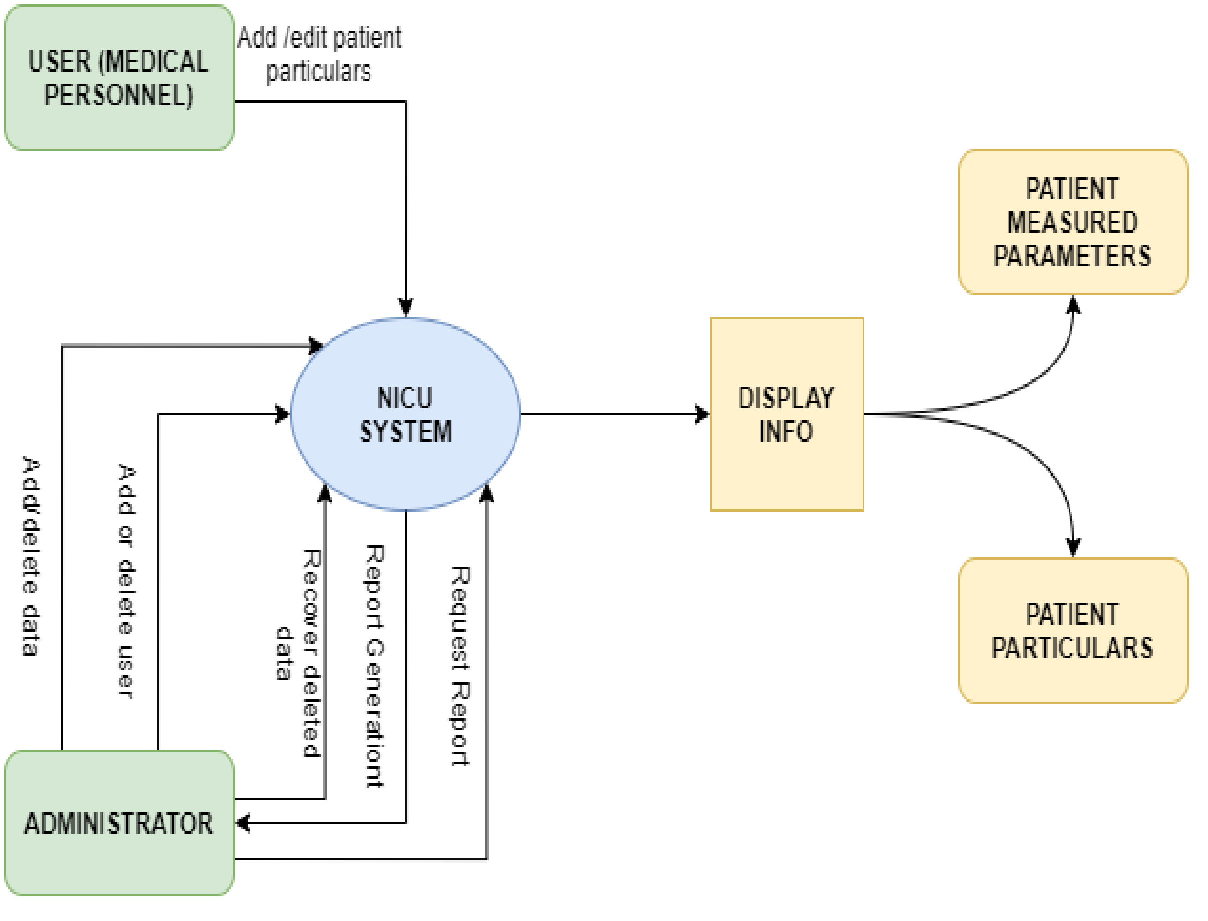


Figure 30: Context diagram

3.7.2 User Login

The user will be requested to provide his or her credentials, including name and password, on the homepage. The system verifies the credentials provided and either denies or grants access to the requested page.

3.7.3 Administrator Login

The process is the same as that user login; the admin will be requested to provide his or her credentials, including name and password, on the homepage. The system verifies the credentials provided and either denies or grants access to the requested page. The page the admin is directed to has more functionalities compared to that of the normal user.

3.7.4 Account Creation

The admins can delete or create an account. The system grants the admin to create an account with the default user name and password which can later be altered by the user.

3.8 System Implementation and Testing

3.8.1 Printed Circuit Board Designing

Proteus 8.9 was used in designing the schematic and PCB layout as shown in Fig. 31. The choice of the tools used was mainly due to availability, ease to use, and loaded with several libraries

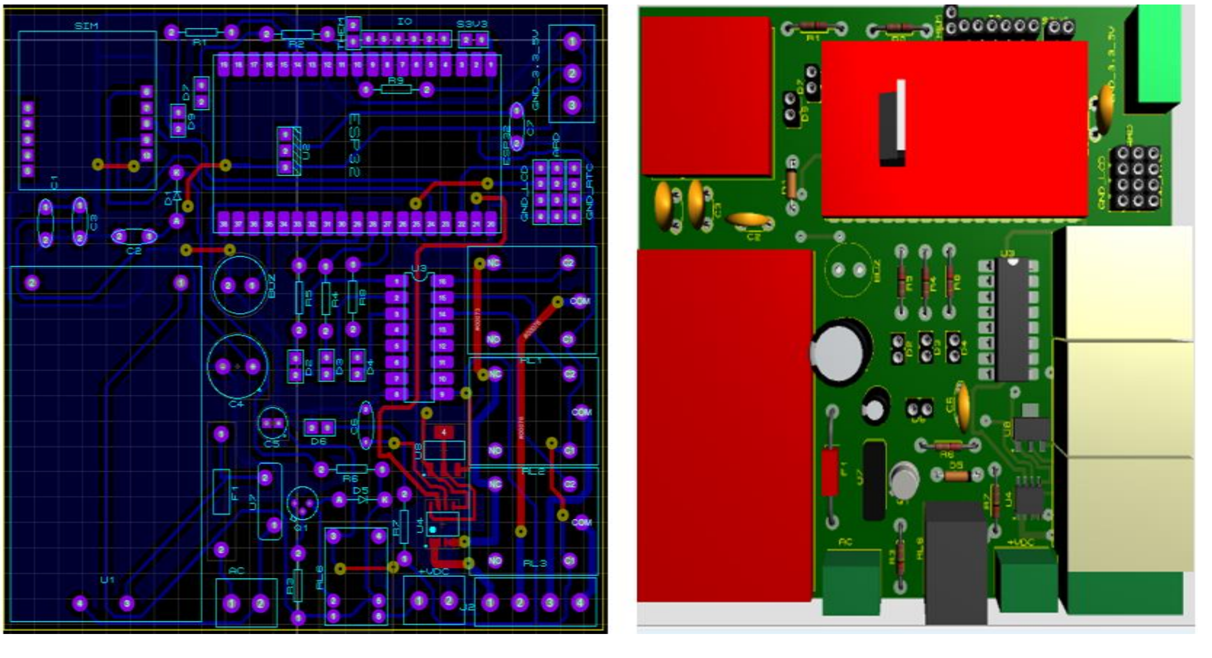


Figure 31: Printed circuit board trace layout and 3D overview

3.8.2 Printed Circuit Board Etching

The designed PCB layout was transferred to a copper-clad board through a heating process to print the circuit on the copper board. The printed circuit was then immersed in $FeCl_3$ solution to remove all copper on the board not protected by the printed ink as shown in Fig. 32. The etched circuit was then populated by several components and soldered.

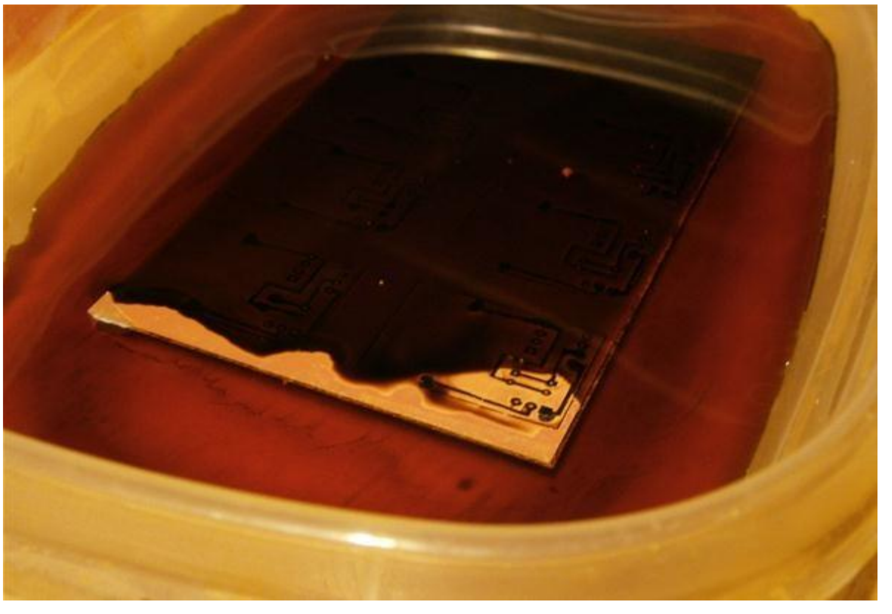


Figure 32: Printed circuit immersed in $FeCl_3$

3.8.3 Prototype Housing

The metal framework and carpentry work as seen in Fig. 33, were done accurately to device a comfortable design that will accommodate the infants ensuring the safety and easy maintenance and operation of the overall developed system.

Figure 33: Top and front overview of the prototype housing

3.8.4 System Testing

Different parts of the system were integrated and tested for their functionality. The developed device was turned on and subjected to various conditions such as icy water and hot temperature from solder wire to observe sensor responses. As in Fig. 34(b), the thermistor was immersed in cold water to obtain the reading as indicated on the screen. The heater turned on as expected to compensate for the temperature. The heart rate and SPO2 values were measured when the finger wasn't placed well on the sensor surface for testing. The web server graph plotted random data as a testing dataset shown in Fig. 34(a)

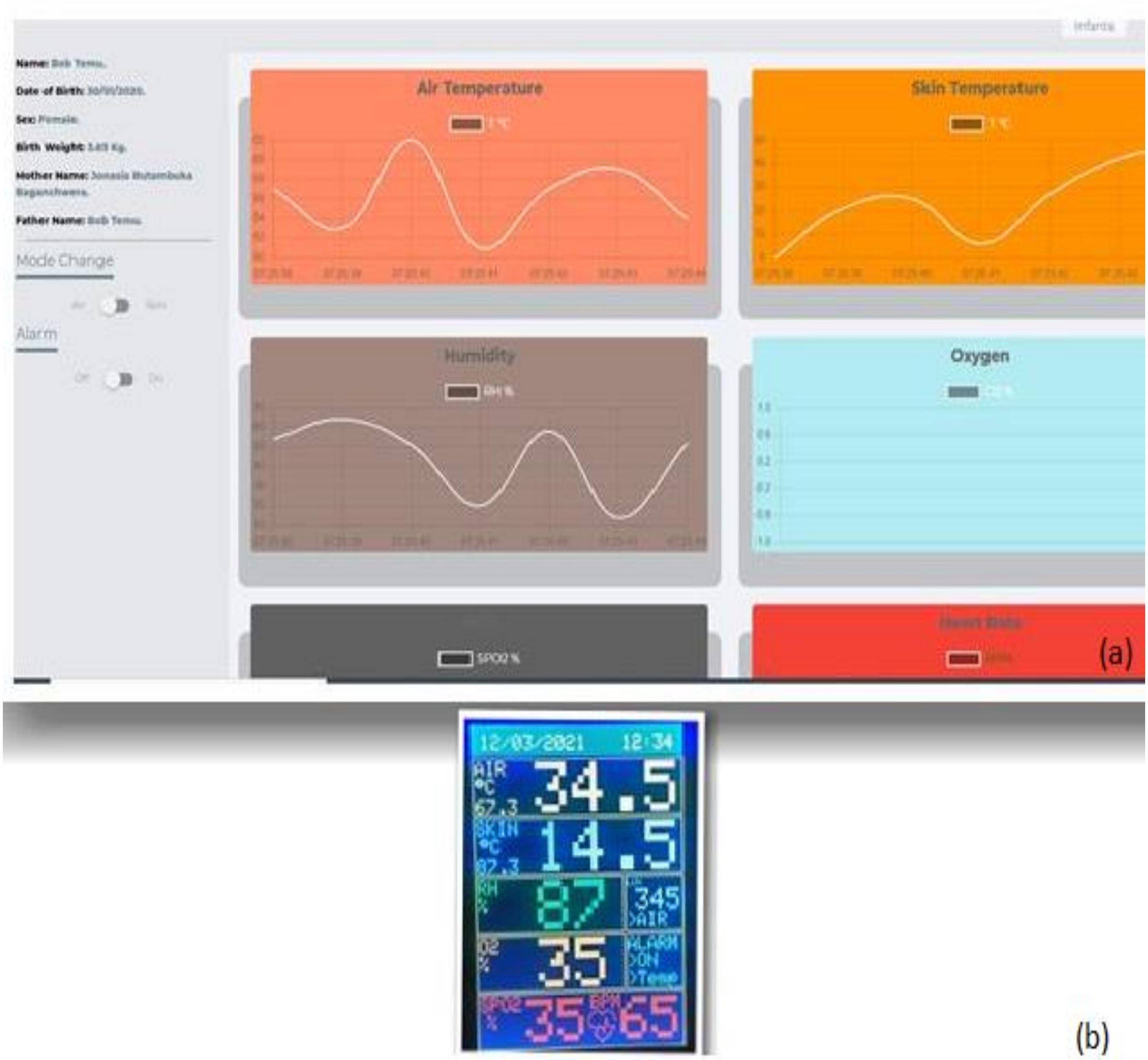


Figure 34: **System testing**

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

This Chapter summarizes the findings of an existing newborn incubator. It includes outcomes from the study, interviews, a survey, a discussion, system requirements and specifications, and system development.

4.1.1 Established Functional and Non-functional Requirements

As shown in Table 6, the results of an interview, observation, consultation, workshop and training proposed the following functional and non-functional items requirements that have contributed to the proposed system's development.

Table 6: Established requirements

Functional Requirements		
SN	**Description**	**Requirements Description**
1	Measure the vital signs using sensors	Environmental temperature, humidity, skin temperature, heart rate, blood oxygen saturation, air quality, and light intensity should be measured
2	Maintain infants parameters within the range	When the measured condition deviates from the present one, the system should change the condition by actuating a corresponding switch
3	Integrate the device with the webserver	The developed system should be able to communicate with the developed web server
4	Submit the measured biological parameter to the webserver	The device should be able to be controlled remotely via the internet through the web server developed
Non-functional Requirements		
1	Maintainability	The facility's biomedical engineering should be able to readily maintain the device
2	Efficiency	The system should complete tasks without wasting time or energy.
3	Ethical	The developed system should conform to generally accepted standards of behaviour

4	Reliability	Perform its intended purpose satisfactorily for a set amount of time, or operate in a specific environment without failing
5	Usability	Simple, allowing easy access to commonly used features or commands

4.1.2 Secondary Data Findings

Documentation and evaluation of other comparable publications revealed that the global infant incubator market is estimated to reach $289.1 million by 2024, with a 6.7% compound annual growth rate (CAGR) over the forecast period. By 2024, the Neonatal Intensive Care Unit (NICU) Incubator Market would have dominated the Global Infant Incubator Market, rising at a CAGR of 6.2%. During the forecast period, the Transport Infant Incubator market is predicted to grow at the fastest rate of 7.5% (2018 - 2024) (KBVresearch, 2018). Figure 35 depicts the distribution of the demanded devices as estimated.

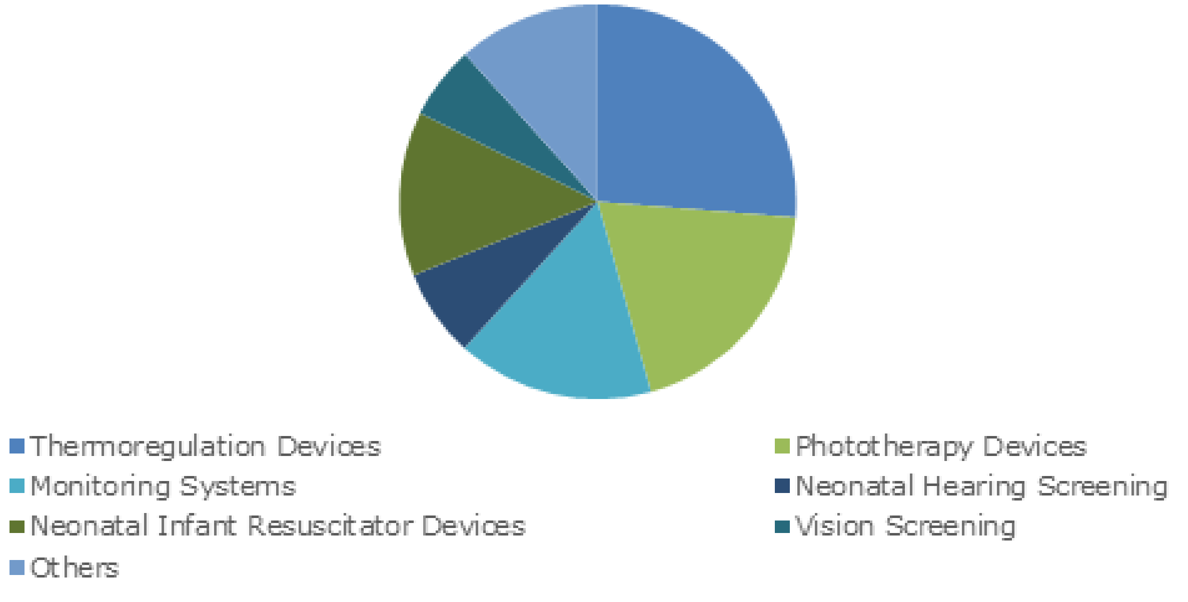


Figure 35: Global NICU market by product type in USD millions by 2019 (KBVresearch, 2018)

The rise in the number of premature deliveries around the world will be a major element driving the neonatal infant care market forward. Thermoregulation, phototherapy, and monitoring devices are incorporated into this project.

4.1.3 Circuit Designing

(i) Simulation Test and Simulation Results

The designed circuit was simulated using Proteus 8.9 and Arduino software. Parts are integrated into an Atmega328 as a testing MCU, as shown in Fig. 36. The simulation demonstrated how the heater and humidifier turn on when temperature and humidity are above or below the set one.

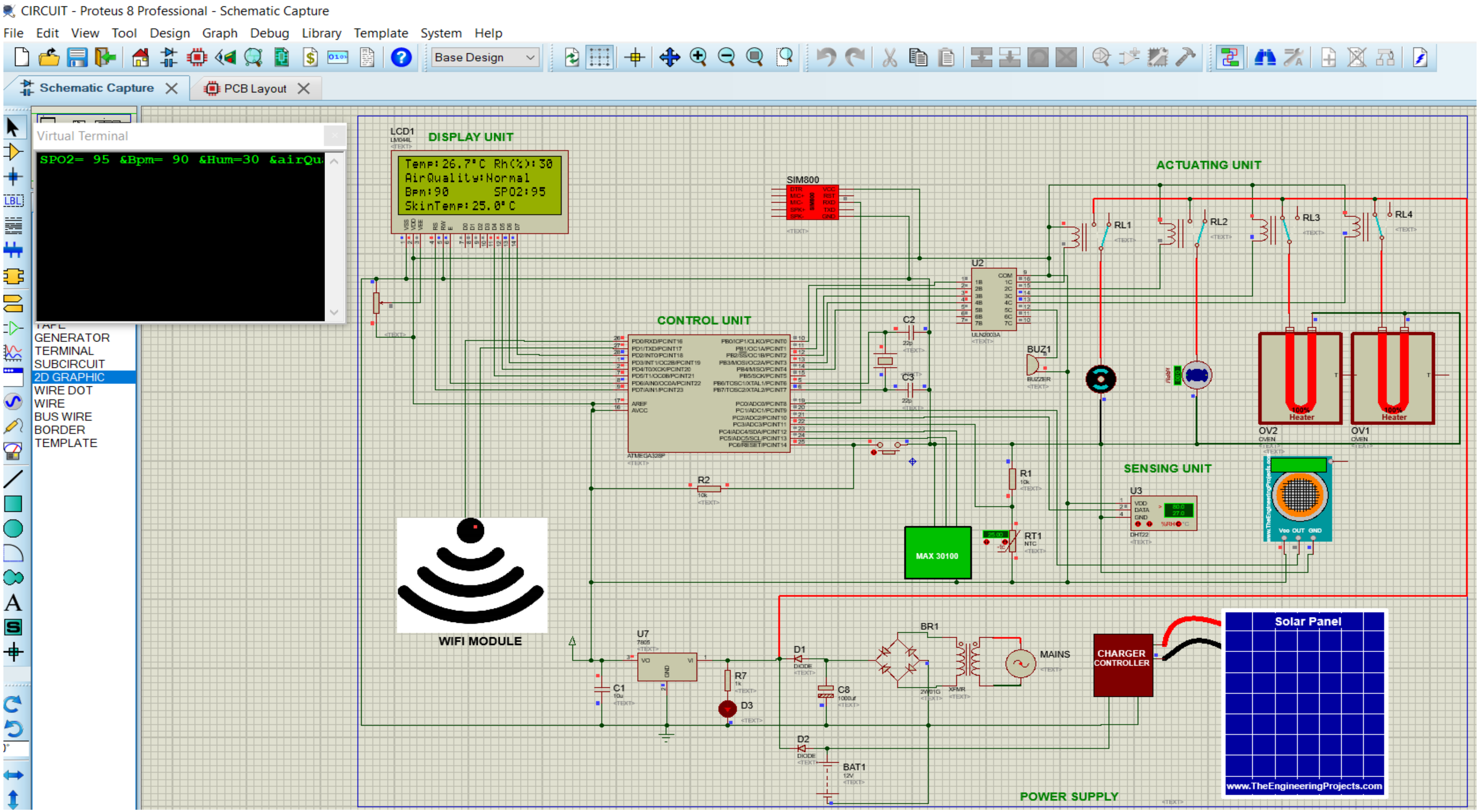


Figure 36: **Circuit Simulation**

(ii) Fabricated PCB and Components Integration

The printed circuit board that was immersed in $FeCl_3$ resulted to Fig. 37(a) showing the traces for the top and bottom layers. The components were mounted and soldered as shown in Fig. 37(b) resulting in a functional circuit shown in Fig. 37.

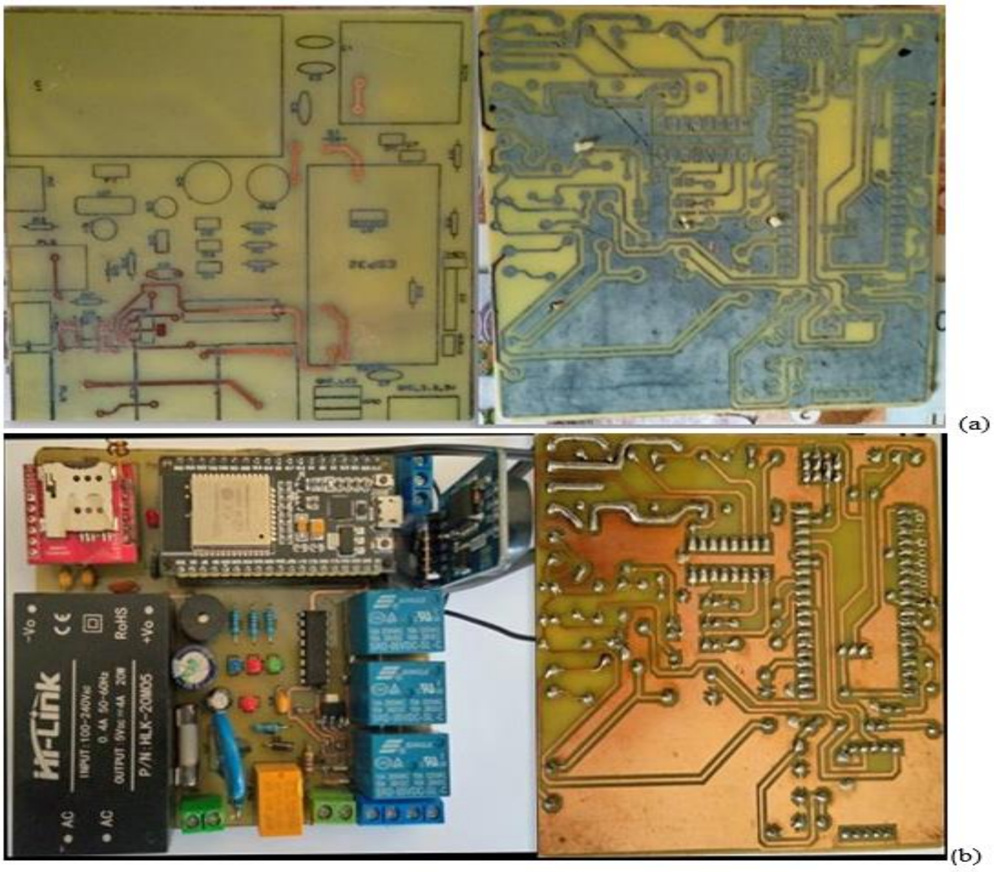


Figure 37: Fabricated PCB and soldered circuit

4.1.4 System Testing

(i) Web Application

The developed system comprises the integration of hardware and software. The interface between the incubator and the software is through Wi-Fi in which all the measured parameters and control commands are sent. Using a mobile phone, computer or any other related smart device will enable the doctor or medical personnel to monitor and control the unit remotely. The software part has the following interface:

User Interface

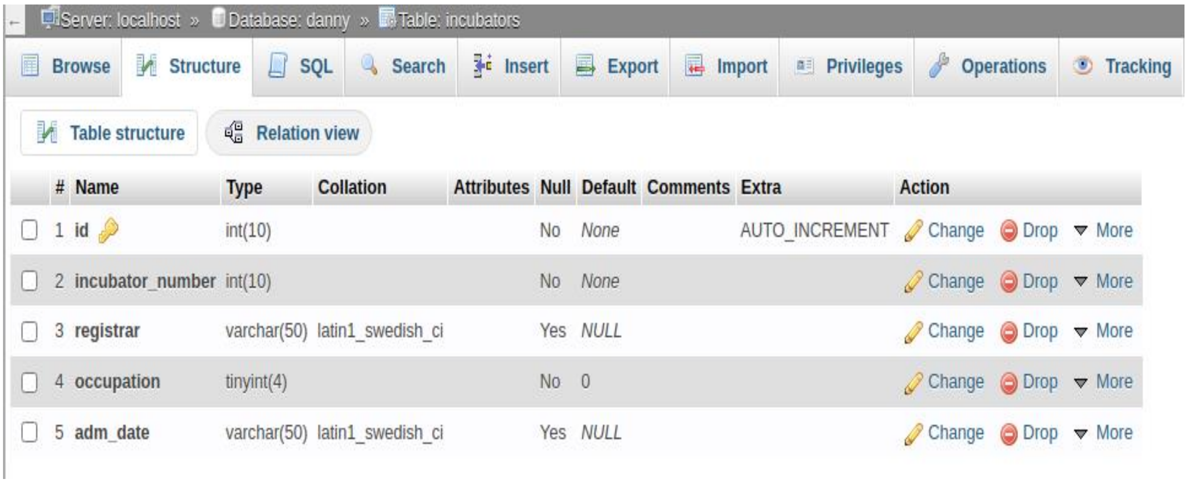
It provides a user with a dashboard with the neonate's particulars, plotting of the measured parameters, changing passwords, tracking the records, and the ability to edit the neonate's details

Admin Interface

The admin interface grants the registration of a new user, delete or modify the existing user along with all other features in the user interface

(ii) Database Design and Implementation

The database was developed and supported by MySQL database management and PHP scripts for users' web connectivity. Figure 38 shows one among several tables used associated with this application


Server: localhost » Database: danny » Table: incubators

Browse | Structure | SQL | Search | Insert | Export | Import | Privileges | Operations | Tracking

Table structure | Relation view

#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action		
1	id	int(10)			No	None		AUTO_INCREMENT	Change	Drop	More
2	incubator_number	int(10)			No	None			Change	Drop	More
3	registrar	varchar(50)	latin1_swedish_ci		Yes	NULL			Change	Drop	More
4	occupation	tinyint(4)			No	0			Change	Drop	More
5	adm_date	varchar(50)	latin1_swedish_ci		Yes	NULL			Change	Drop	More

Figure 38: Designed database

Although MongoDB is well-suited for real-time analytics, and content management which is similar in nature to that of this project but MySQL was used. The main reason why MySQL was the best choice is due to the fact that: Supports for memory storage engine for frequently used tables, Query Cache for repeatedly used statements and It has a large supporting community that you can easily learn and troubleshoot MySQL from different sources like blogs, white papers, and books.

Input and Output Design

The application developed is dynamic and responsive for different smart tools such as laptops, desktops, smartphones, etc. It provides an interface to the medical personnel enabling them to monitor and control the unit remotely.

Login Page

The login page as displayed in Fig. 39 provides a welcome message and a login panel where the user is required to provide the correct credentials to have access to the system. Once the user access is granted, will be directed to the page based on their privileges

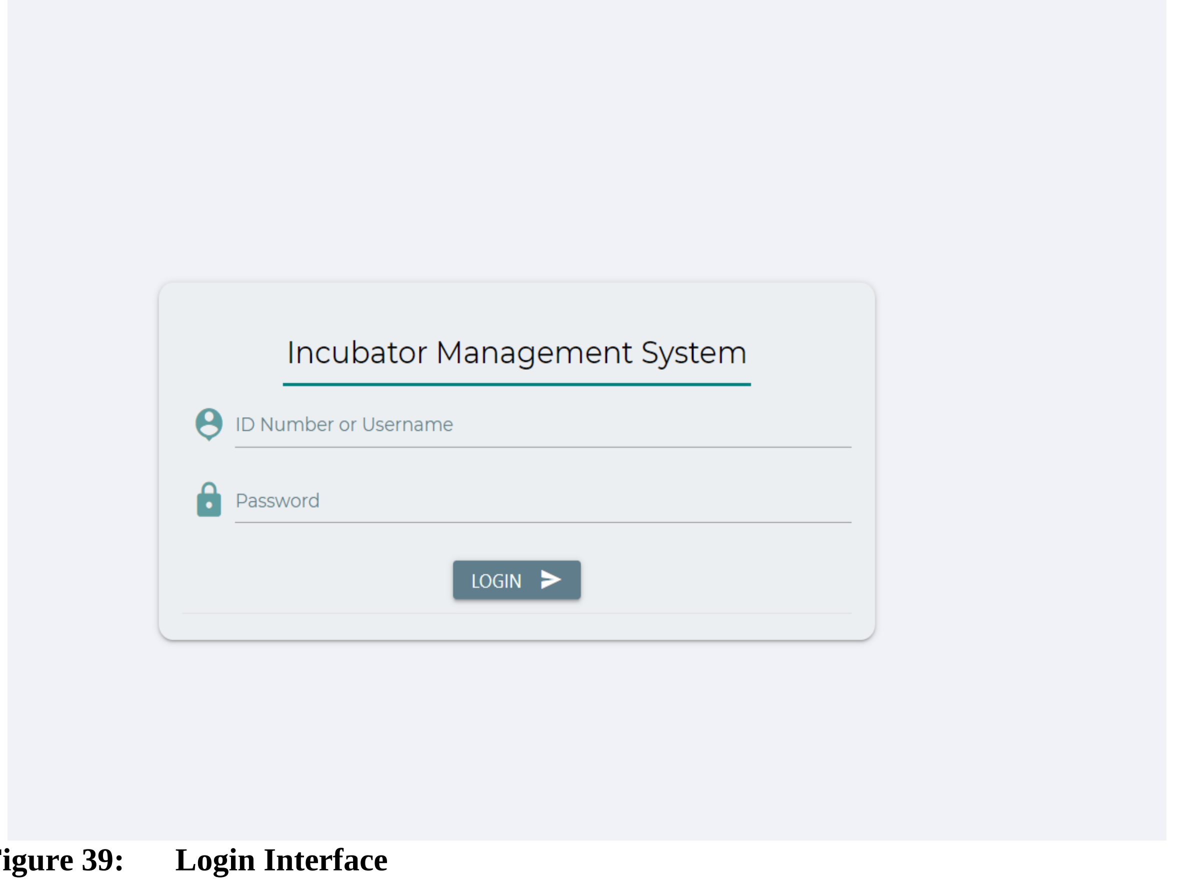


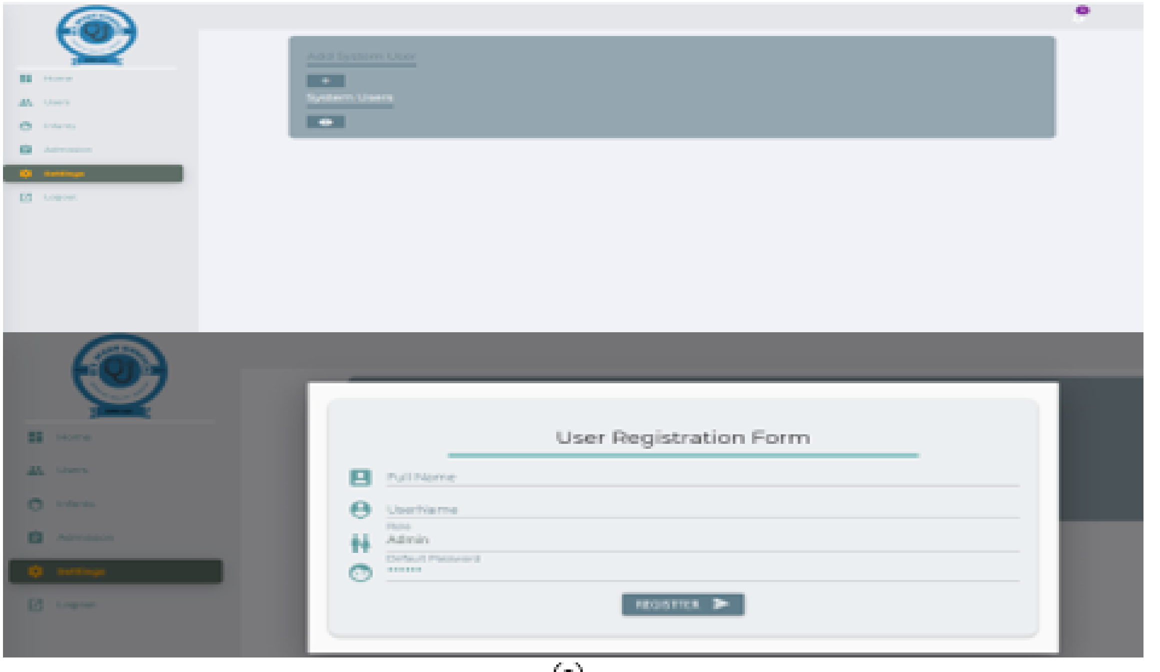
Figure 39: Login Interface

Dashboard

The dashboard contains the neonate's details and the plots of the measured parameters. It is through here that the doctor can monitor, set, and control the unit.

User and Infant Registration

Administrators can register a new user in the system or delete them as shown in Fig. 40(a). Users are obligated to provide personal details such as name in full, telephone number, department, etc. The system will provide a username and a default password of the newly created user. The infant's particulars are registered to the system as seen in Fig. 40(b).



(a)

(b)

Figure 40: Registration forms

(iii) The Incubator

The incubator is the hardware part of the developed system. It mainly consists of the control unit (ESP32 as MCU), actuating unit, and the display and alerting section. Several tests were undergone and recorded as shown in Table 7 and Fig. 41. Three subjects involved in the tests were all placed in different environments for testing purposes.

Test Results

Figure 41 and Table 7 show results obtained from three specimens, and the last test is without any specimen to oversee how the system behaves. During testing, the system was linked to the web server for remote data monitoring.

Table 7: Observed test

Trial	Sample	Gender	Age	Heart Rate (Bpm)	SpO2 (%)	Skin Temp. (^{o}C)	Air Temp. (^{o}C)	Humidity (%)	Air Quality (%)
1	Specimen 1	M	5-10	78	96	36.7	28.1	78	92
2	Specimen 2	M	10-15	80	94	36.4	28.5	76	92
3	Specimen 3	F	25-30	76	98	37.1	29.o2	80	92
4	No specimen	-	-	0	0	30.6	46.5	40	93

Figure 41: Tests results

Figure 41 displays the SMS sent to medical personnel registered mobile phone numbers from the system in case of any alert so that further immediate action can be taken.

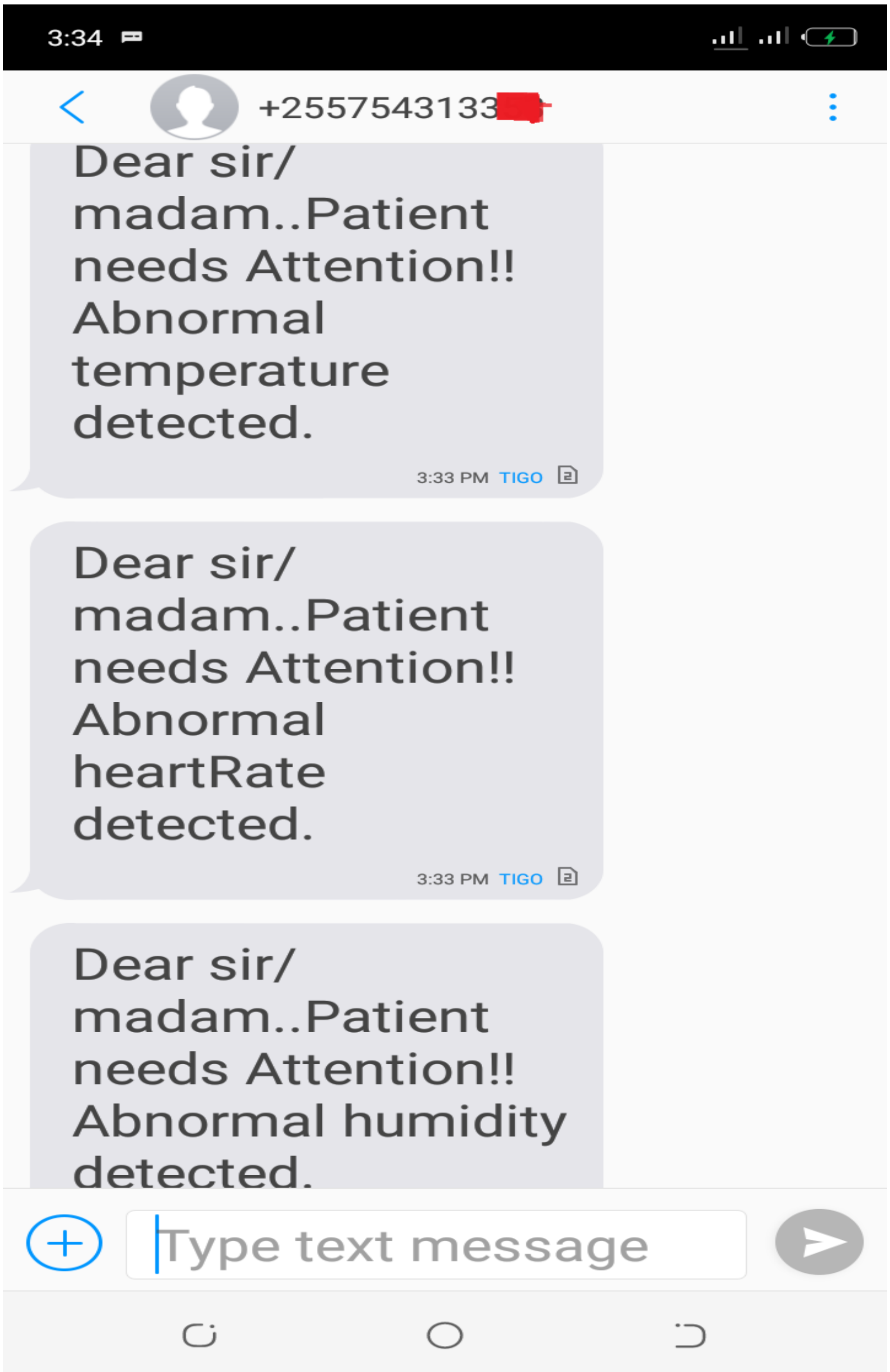
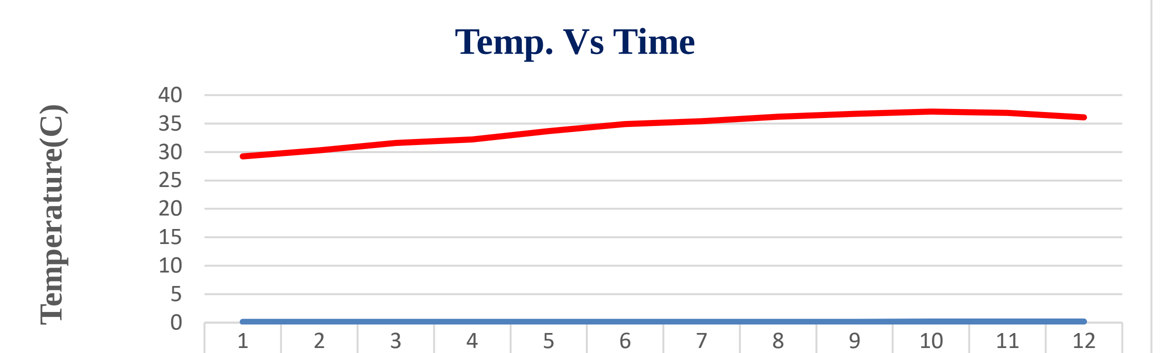


Figure 42: SMS notification

Temperature regulation is a crucial component in any incubator. Temperature versus time was recorded to note the regulation pattern. The baby chamber size and the heater wattage determine the time for the system to stabilize the temperature from its initial condition of about 28-30^{o}C to the set one. The heater is turned on when the measured temperature falls below the predetermined value, depending on the mode of operation. In Fig. 43 it is temperature versus time characteristics plotted during testing. The time for temperature rise depended on the size (wattage) of the heater used and the baby chamber size.



	1	2	3	4	5	6	7	8	9	10	11	12
Temp.(C)	29.2	30.3	31.6	32.2	33.7	34.9	35.4	36.2	36.7	37.1	36.9	36.1
Time	03:30:	03:30:	03:31:	03:31:	03:32:	03:32:	03:33:	03:33:	03:34:	03:35:	03:40:	03:42:

Figure 43: Temperature regulation characteristics

4.1.5 The Developed Prototype

By using CAD tools, the neonate's housing was designed. Welding the metal framework, carpentry work as per the design, and electrical and electronics system installation resulted in a comfortable room for the neonate growth. Figure 44 shows the developed prototype in the final stage.

Figure 44: Final prototype

(i) Attributes of the Developed System

Neonatal care and monitoring units or the incubator have been around for some time. Various approaches and technology have been deployed to save the life of infants. Table 8 lists the feature incorporated in the proposed and developed system.

Table 8: Attributes of the developed system

S. No	Attribute	Description
1	Real-time remote monitoring and control	The measured data are timely provided via the internet or GSM
2	Reliable, accurate, and low cost	The sensors are calibrated to the standard one and the developed system is cost-effective
3	Multi powered	The unit can be powered by main, solar, or alike. Making it a perfect choice in rural areas

(ii) Cost Analysis

Many manufacturers in the market produce this product and among the popular ones are Airborne, Air-Shields, Ardo, Atom, Japan, Datex-Ohmeda, Drager, GE, Guido Rayos, Hill-Rom, OGB and Ohio Medical. According to site survey from different e-commerce websites including Aliexpress and eBay. Table 9 shows the type and the cost of the incubator of a similar kind in the market.

Table 9: Price list of the incubators in the market

Name and Model No.	Source	Price
Hospital Infant Radiant Warmer Neonate Bilirubin Phototherapy Equipment Baby Infant Incubator HF-3000A/3000B	Aliexpress	$4000-$6000
Infant Baby Incubator Neonatal Intensive Care Unit LABGO 101	eBay	$3400-4000
Mic-02 infant baby transport incubator neonatal intensive care unit with backup	eBay	$3000-$3500
GE Giraffe Infant Incubator	eBay	$4300-$5000

As shown in Table 9, the average price of an incubator ranges from $3000 to $6000 without including transportation and tax.

The Cost of the Developed Prototype

Direct costs would be direct labour involved in manufacturing, inventory, raw materials and manufacturing expenses.

Table 10: Estimated used project cost

Attribute	**Specification**	**Cost**
	Direct cost	
Materials	Control unit and actuators	$150
Labour involved	Carpentry	$100
	Welding	$100
	Aluminium and glass work	$100
	Other costs	
Indirect cost	Risk potential cost and other intangible costs	$100
	Estimated total	$550

The estimated used cost may vary accordingly.

4.2 Discussion

The test conducted proves systems reliability and efficiency in controlling and monitoring the premature baby's vital signs. The skin and surrounding temperature, humidity, heart rate, blood oxygen saturation, and light intensity for phototherapy treatment were monitored and controlled. As shown in Fig. 44, the final prototype comprises a well-designed housing with a transparent glass baby chamber, a height-adjustable unit, and drawers to keep diapers, medicine, and other related necessities.

The login page, user registration form, and newborn registration form are all included in the built web server, as shown in Fig. 39 and 40(a)(b). The system rejects all other users and only accepts registered users who provide proper credentials. 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 Fig. 40(b).

The test involved several tests shown in Table 7 showing the results from the four tests. The data ware presented on a widescreen monitor, as shown in Fig. 41, and updated to the website every five seconds. Figure 41 also represents the visualization of the specimen involved and the data of temperature, humidity, heart rate, and blood oxygen saturation was sent to the webserver. The deviation of the measured parameter from set one leads to the actuation of the process in which the heater is turned on to warm the baby's environment in all specimen trials mainly because the set temperature is above the measured.

The last trial did not involve any specimen and the hot gun placed near the sensor resulted in temperature rise and humidity drop. The situation encountered triggered an alarm and humidification process to compensate for relative humidity and the cooling process by turning on a cooling fan to lower the temperature. The device can be remotely controlled as Fig. 41 shows the dashboard with infants' particulars and the visualization of the measured parameters from the incubator along with control buttons. As in Fig. 42, abnormal temperature, humidity, and heart rate triggered an alert SMS sent to medical personnel whenever such critical conditions were encountered.

Furthermore, it has been noted that the designed system took 3-4 minutes to adjust the chamber temperature ranging from 28-30^{o}C to the pre-set one of 37^{o}C as shown in Fig. 43. Based on this system testing, results, and analysis carried out during the project implementation, the system’s reliability, affordability, accuracy, efficiency and effectiveness are guaranteed.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Childbirth complications have been a challenge in the health sector, neonates' deaths have been estimated among the five leading sources of death in the world as per UNICEF, USAID, and WHO estimates (WHO, 2006). Among the policies in the Ministry of health and social welfare, is the national road map strategic plan which aims at accelerating the reduction of maternal, newborn, and child deaths in Tanzania. The aim of this project it reduces the mortality rate by designing and developing a low-cost, effective, reliable, and easy-to-use infant incubator that will ensure the safety of babies who are born with complications by providing efficiency and effective care to support their growth. The target of the Ministry can only be achieved by continuous measuring of the vital signs to ensure efficient hold-up of neonates and management of all information concerned with the newborns at the hospital. By measuring and controlling the vital signs such as baby skin temperature, heart rate, blood oxygen saturation, the surrounding temperature, and humidity along with phototherapy complications such as jaundice, hypoxia and hypothermia may lead to a rapid reduction of neonatal death and other complications. From the gaps presented in the existing systems, the following were addressed in this project:

(i) When compared to the equipment utilized in existing systems, the equipment used for system development was very affordable. Typically, most of the incubators cost as higher as 6000$ but the developed prototype costs as little as 550$ and the cost may rise slightly when put into a useful final product.

(ii) The developed system is user-friendly as it is straightforward, providing quick access to common features or commands.

(iii) The developed system featured both English and Kiswahili language.

(iv) The system can be powered by both mains supply and an alternative source such as solar or alike making it suitable in rural areas where mains power is unavailable or unreliable.

5.2 Recommendations

Based on the innovative functionalities and features of this system, we recommend the Ministry of health and social welfare to:

(i) Deploy the developed system in various health care institutions given that it is homemade (made in Tanzania), reliable, and of low cost

(ii) To allow the incubator to transfer data to a web page for remote data control and monitoring, the hospital must have an internet connection point.

(iii) Standardization and regulatory bodies such as TBS (Tanzania Bureau of Standards) and TMDA (Tanzania Medicines and Medical Devices Authority) must provide an easy way to assess the functionality of the locally developed systems to be implemented successfully.

(iv) Other researchers to research further in the area and integrate other emerging technologies such as artificial intelligence (AI) and machine learning (ML) to enhance early control through the prediction of the infants' outcomes before, during, and after birth. This will guarantee the neonate's safety since preconditions or attendance will be taken and measured as early as possible.

REFERENCES

Abbas, M. W., Shamshad, T., Ashraf, M. A., & Javaid, R. (2016). Jaundice: A basic review. *Journal of Research in Medical Sciences*, *4*(5), 1313-1319.

Afnan-Holmes, H., Magoma, M., John, T., Levira, F., Msemo, G., Armstrong, C. E., Martínez-Álvarez, M., Kerber, K., Kihinga, C., Makuwani, A., & Rusibamayila, N. (2015). Tanzania's countdown to 2015: An analysis of two decades of progress and gaps for reproductive, maternal, newborn, and child health, to inform priorities for post-2015. *The Lancet Global Health,* 3(7), e396-e409.

Aslam, H. M., Saleem, S., Afzal, R., Iqbal, U., Saleem, S. M., Shaikh, M. W. A., & Shahid, N. (2014). Risk factors of birth asphyxia. *Italian Journal of Pediatrics,* 40(1), 1-9.

Butler, A. S., & Behrman, R. E. (Eds.). (2007). *Preterm Birth: Causes, Consequences, and Prevention.* National academies press. https://scholar.google.com

Bouwstra, S., Chen, W., Feijs, L., & Oetomo, S. B. (2009). *Smart Jacket Design for Neonatal Monitoring with Wearable Sensors. The 2009 Sixth International Workshop on Wearable and Implantable Body Sensor Networks.* https://www. google.com

Cabacungan, P. M., Oppus, C., Tangonan, G. L., Cabacungan, N. G., Mamaradlo, J. P., & Mercado, N. A. (2020). *Design and Development of Electronic Sensor and Monitoring System of Smart Low-cost Phototherapy Light System for Non-Invasive Monitoring and Treatment of Neonatal Jaundice*. https://www. google.com

CDC. (2020). *Preterm Birth.* https://www. google.com

Chee, Y. Y., Chung, P. H., Wong, R. M., & Wong, K. K. (2018). Jaundice in infants and children: Causes, diagnosis, and management. *Hong Kong Medical Journal,* 24(3), 285-92.

Espressif Inc. (2018). *ESP32-WROOM-32 (ESP-WROOM-32) Datasheet*. https://www. google.com

Fahmi, F., Shalannanda, W., Zakia, I., & Sutanto, E. (2020). *Design Of an Iot-Based Smart Incubator that Listens to the Baby. In IOP Conference Series: Materials Science and Engineering.* IOP Publishing. https://www. google.com

Hey, E. N., & Mount, L. E. (1967). Heat losses from babies in incubators. *Archives of Disease in Childhood*, 42(221), 75.

Jabbar, W. A., Shang, H. K., Hamid, S. N., Almohammedi, A. A., Ramli, R. M., & Ali, M. A. (2019). IoT-BBMS: Internet of Things-based baby monitoring system for smart cradle. *Access*, 7, 93791-93805.

KBVresearch. (2018). *Infant Incubator Market Size*. https://www.kbvresearch.com/infant-incubator-market/table-of-content/

Lawn, J. E., Cousens, S., Zupan, J., & Lancet Neonatal Survival Steering Team. (2005). 4 million neonatal deaths: When? Where? Why? *The Lancet*, 365(9462), 891-900.

Liu, T. (2013). *Digital-Output Relative Humidity & temperature Sensor/Module DHT22 (DHT22 also Named as AM2302).* Aosong Electronics.[En línea]. Disponible: https://www. sparkfun. com/datasheets/Sensors/Temperature/DHT22.

Lyon, A. J., Pikaar, M. E., Badger, P., & McIntosh, N. (1997). Temperature control in very low birthweight infants during first five days of life. *Archives of Disease in Childhood-Fetal and Neonatal Edition*, 76(1), F47-F50.

Maisels, M. J., & McDonagh, A. F. (2008). Phototherapy for Neonatal Jaundice. *New England Journal of Medicine*, 358(9), 920-928.

Mandke, S., Kudave, K., Labde, R., & Bakal, J. W. (2018). IOT based Infant Health Monitoring System. *International Journal of Engineering and Technology*, 5(4), 3418-3421.

McCormick, M. J. M. (2012). *Waterfall Vs. Agile Methodology*. https://www. google.com

Meyer, M. P., Payton, M. J., Salmon, A., Hutchinson, C., & De Klerk, A. (2001). A clinical comparison of radiant warmer and incubator care for preterm infants from birth to 1800 grams. *Pediatrics*, 108(2), 395-401.

Ministry of Health and Social Welfare. (2015). *Tanzania Service Provision Assessment Survey (TSPA) 2014-15*. https://www. google.com

Mittal, H., Mathew, L., & Gupta, A. (2015). Design and development of an infant incubator for controlling multiple parameters. *International Journal of Emerging Trends in Electrical and Electronics*, 11(5), 65-72.

Plan, S. O. (2014). *The National Road Map Strategic Plan to Accelerate Reduction of Maternal, New born and Child Deaths in Tanzania 2008-2015*. https://www. google.com

Newman, T. B., Kuzniewicz, M. W., Liljestrand, P., Wi, S., McCulloch, C., & Escobar, G. J. (2009). Numbers needed to treat with phototherapy according to American Academy of Pediatrics guidelines. *Pediatrics*, 123(5), 1352-1359.

Nicuawareness. (2021). *A Brief History of Advances in Neonatal Care*. https://www. google.com

Nivetha, B., & Kumar, E. S. M. (2020). Iot based nicu baby healthcare monitoring system. *Materials Today: Proceedings*, 33, 4837-4841.

Rastogi, V. (2015). Software development life cycle models-comparison, consequences. *International Journal of Computer Science and Information Technologies*, 6(1), 168-172.

Romero, R., Dey, S. K., & Fisher, S. J. (2014). Preterm labor: one syndrome, many causes. *Science,* 345(6198), 760-765.

Sendra, S., Romero-Díaz, P., Navarro-Ortiz, J., & Lloret, J. (2018). *Smart infant incubator based on LoRa networks. The 2018 IEEE/ACS 15th International Conference on Computer Systems and Applications.* https://www. google.com

Shabeeb, A. G., Al-Askery, A. J., & Nahi, Z. M. (2020). Remote monitoring of a premature infants incubator. *Indonesian Journal of Electrical Engineering and Computer Science*, 17(3), 1232-1238.

Shaib, M., Rashid, M., Hamawy, L., Arnout, M., El Majzoub, I., & Zaylaa, A. (2017). *Advanced portable preterm baby incubator. The 2017 Fourth International Conference on Advances in Biomedical Engineering*. https://www. google.com

Shapiro-Mendoza, C. K., Barfield, W. D., Henderson, Z., James, A., Howse, J. L., Iskander, J., & Thorpe, P. G. (2016). CDC grand rounds: public health strategies to prevent preterm birth. *Morbidity and Mortality Weekly Report,* 65(32), 826-830.

Simbruner, G., Ruttner, E. M., Schulze, A., & Perzlmaier, K. (2005). Premature infants are less capable of maintaining thermal balance of head and body with increases of thermal environment than with decreases. *American Journal of Perinatology*, 22(01), 25-33.

SIMCom Wireless Solution Co.L. (2013). *Datasheet_SIM800L*. https://www. google.com

Singla, S. K., & Singh, V. (2015). Design of a microcontroller based temperature and humidity controller for infant incubator. *Journal of Medical Imaging and Health Informatics*, 5(4), 704-708.

Sony, M. D., Isaac, J. S., Ezhilarasi, N., & Jayanth, V. (2021, June). IOT Based Infant Healthcare Monitoring System. *Journal of Physics: Conference Series,* 1937 (2021) 012050

Srikanth, B., Divya, P., Nandini, P., Sabira, S., & Bharathi, T. (2020). Patient Health Monitoring using Arduino through IoT. *International Journal of Research & Development,* 2020, 619-633.

Thomas, K. A., & Burr, R. (1999). Preterm infant thermal care: differing thermal environments produced by air versus skin servo-control incubators. *Journal of Perinatology,* 19(4), 264-270.

Tran, K., Gibson, A., Wong, D., Tilahun, D., Selock, N., Good, T., Ram, G., Tolosa, L., Tolosa, M., Kostov, Y., & Woo, H. C. (2014). Designing a low-cost multifunctional infant incubator. *Journal of Laboratory Automation,* 19(3), 332-337.

Turk, E. E. (2010). Hypothermia. *Forensic Science, Medicine, and Pathology,* 6(2), 106-115.

UNICEF. (2007). *The state of the world's children 2008: Child survival* (Vol. 8). Unicef. https://www. google.com

Verywell family. (2021). *How an Incubator Works in the NICU*. https://www. google.com

Weithoner, F. (2022). *InfantIncubator*. https://www. google.com

WHO. (2003). *Kangaroo Mother Care: A Practical Guide*. World Health Organization. https://www. google.com

WHO. (2006). *Neonatal and Perinatal Mortality: Country, Regional And Global Estimates*. World Health Organization. https://www. google.com

APPENDICES

Appendix 1: Data collection Instrument

Neonatal Unit at Mt. Meru Hospital

Participants: Physicians, Nurses, and Hospital Engineer

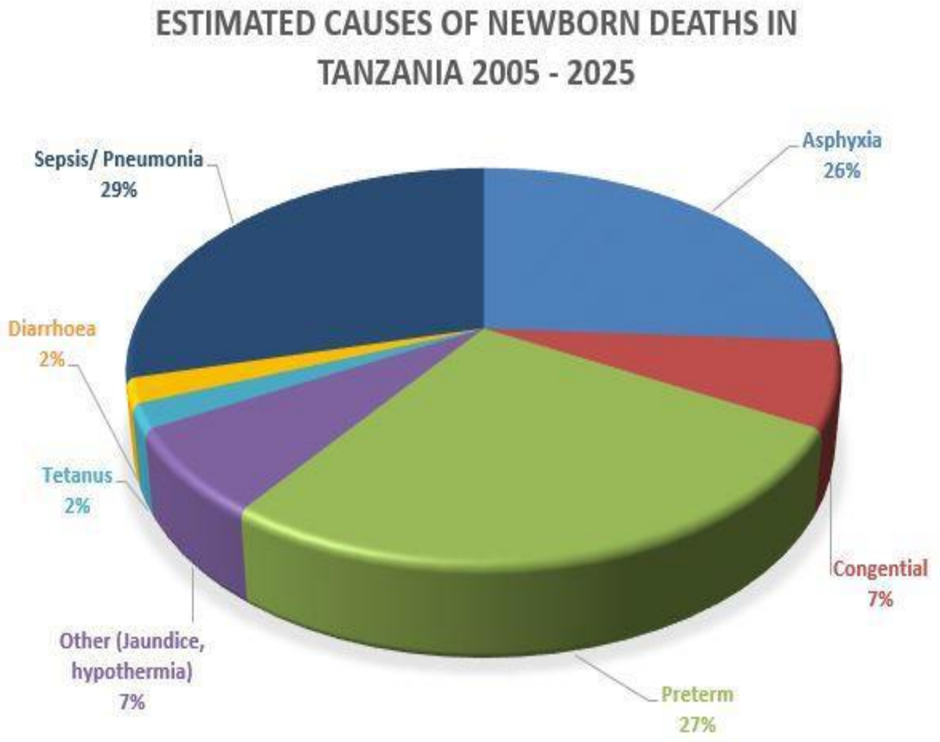
Methods of Data Collection: Observation and Interview

Table 11: Summary of Data analysed from Mt. Meru Hospital

SECTION	PROCESS	DEVICES/MEASUREMENT PARAMETER
	Diagnosis – Glucose level	• Glucometer
INTENSIVE CARE UNIT SECTION	Monitoring	• Body temperature • Pulse rate • Oxygen saturation
	Control-Room temperature	• Manually operated heater
	Ventilation support	• Oxygen concentrators • Ventilator
	Therapy-jaundice	• Phototherapy
TREATMENT SECTION	Diagnosis	• Observation through • skin, gums, and urine
	Paperwork	• Books
DATA RECORDS	Digital	• Microsoft Excel
POWER BACK UP SYSTEM	Solar power	• Lamp, patient monitor, oxygen concentrator
	Backup generator	• The whole hospital facilities

Raw Data

The following data can be used to make the data accessible for additional processing and analysis in a variety of ways. From 2009 to 2021, the Tanzania infant mortality rate was calculated based on the birth and death of new born babies in the country (Tanzania Infant Mortality Rate 1950-2020 | Macro Trends, n.d.).


ESTIMATED CAUSES OF NEWBORN DEATHS IN TANZANIA 2005 - 2025
Sepsis/ Pneumonia 29%
Asphyxia 26%
Diarrhoea 2%
Tetanus 2%
Congential 7%
Other (Jaundice, hypothermia) 7%
Preterm 27%

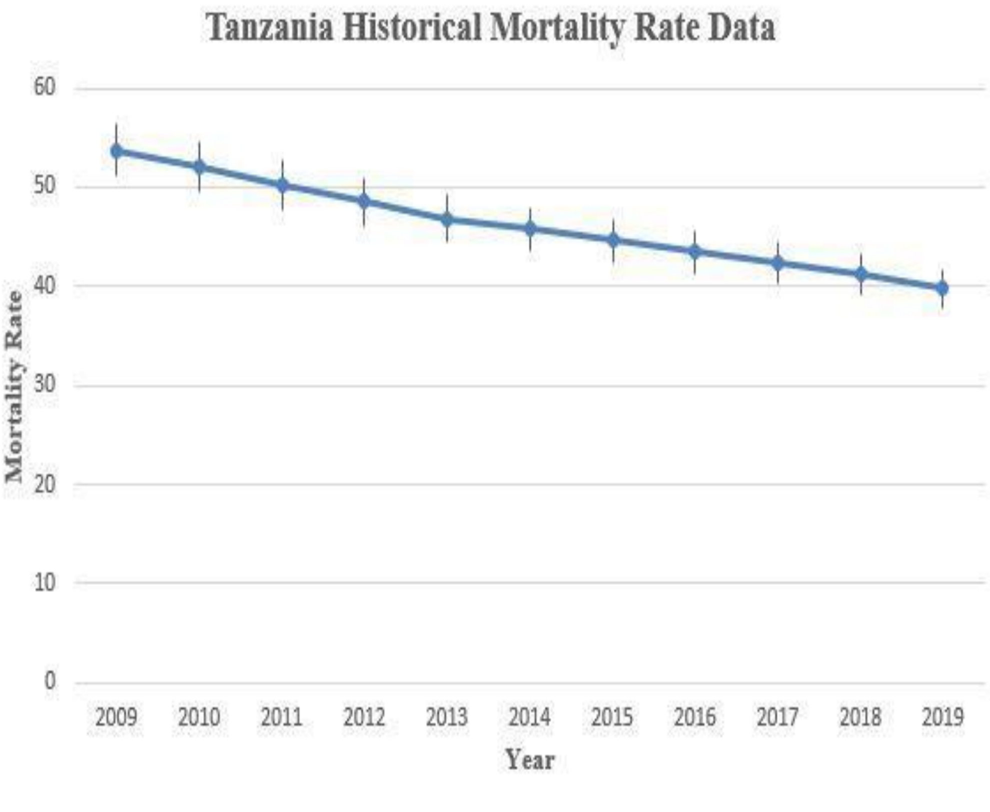

Tanzania Historical Mortality Rate Data
Mortality Rate
60
50
40
30
20
10
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Year

Table 12: Tanzania infant mortality rate trend

Year	Mortality rate	Growth rate
2020	36.983	-3.67%
2021	38.391	-3.54%
2019	53.753	-3.42%
2018	52.03	-2.67%
2017	50.307	-2.60%
2016	48.584	-2.54%
2015	46.861	-2.47%
2014	45.73	-2.41%
2013	44.599	-3.55%
2012	43.468	-3.42%
2011	42.337	-3.31%
2010	41.206	-3.21%
2009	39.798	-3.11%

Appendix 2: Sample of code used

Sample code for incubator system

```
#include <Arduino's>
#include <Wire's>
#include "D.Ph."
#include <Waifish>
#include <WiFiClient.h>
#include <HardwareSerial.h>
#include <HTTPClient.h>
#include "MAX30100_PulseOximeter.h"
//HardwareSerial myGSM(23, 26);

#define Heater 5
#define Humidifier 18
#define oValve 19
#define coolingFan 32
#define airFan 33
#define powerChanger 25
#define mainsRead 17
#define Buzzer 15
#define DHTPIN 34
#define MQ 39
#define tempSensor 26 //33
#define LED1 27
#define LED2 12
#define DHTTYPE DHT22
#define REPORTING_PERIOD_MS 5000
#define dataLog 2000

// Creating WiFiClient object
WiFiClient client;

char Tm = 0, heaterTm = 0, humidTm = 0, oxygenTm = 0;
double tsLastReport1 = 0, tsLastReport2 = 0;

//char* ssid = "ETLAB";
//char* pasword = "Electronics2022_ET"; //char auth[] =
"N6hddK0gI3zsi2n99spENpx38ahYLJPj";

char* ssid = "Alpha G";
char* pasword = "4CENTS90"; //char auth[] = "N6hddK0gI3zsi2n99spENpx38ahYLJPj";

float airTemp, skinTemp, setaTemp, setsTemp, Temp, msdVoltage, R;
int Hum, airQuality, SPO2, Bpm, Lux, Alarm = 0;
bool controlMode = false, AlarmON = false, sms = true, nwConnect = false, mains;
String Msg;

DHT dht(DHTPIN, DHTTYPE);
PulseOximeter pox;
void SendSms(String message);

void onBeatDetected()
```

```
{
  digitalWrite(Buzzer, HIGH);
  delay(10);
}

void setup()
{
  //configuration
  pinMode(Heater, OUTPUT);
  pinMode(Humidifier, OUTPUT);
  pinMode(oValve, OUTPUT);
  pinMode(coolingFan, OUTPUT);
  pinMode(Buzzer, OUTPUT);
  pinMode(airFan, OUTPUT);
  pinMode(MQ, INPUT);
  pinMode(tempSensor, INPUT);
  pinMode(mainsRead, INPUT);
  pinMode(LED1, OUTPUT);
  pinMode(LED2, OUTPUT);
  pinMode(powerChanger, OUTPUT);
  pinMode(17,INPUT);
  dht.begin();
  Wire.begin();
  Serial.begin(9600);
  Wire.setClock(10000);
  delay(10); //initial display on LCD

  //WiFi connection
  WiFi.begin(ssid, pasword); // Attempt to connect to wifi with our password
  char i = 0;
  while (WiFi.status() != WL_CONNECTED)
  {
   Serial.print(".");
   delay(100);
  }
  //Max initialization
  if (!pox.begin())
  {
    Serial.println("FAILED");
    digitalWrite(LED2, LOW);
  }
  else
  {
    Serial.println("SUCCESS");
    digitalWrite(LED2, HIGH);
  }
  pox.setIRLedCurrent(MAX30100_LED_CURR_7_6MA);
  pox.setOnBeatDetectedCallback(onBeatDetected);
  delay(20);
}
//main cycle
void loop()
```

```
{
  //Heart Rate measurement
  pox.update();
  if (millis() - tsLastReport1 > REPORTING_PERIOD_MS)
  {
    Bpm = pox.getHeartRate();
    SPO2 = pox.getSpO2();
    tsLastReport1 = millis();
  } //Heart Rate measurement

  //Sensor read and quantization
  Hum = dht.readHumidity();
  airTemp = dht.readTemperature();
  airQuality = map(analogRead(MQ), 0, 4096, 0, 1023);
  msdVoltage = analogRead(tempSensor) * (3.3 / 4095.0);
  R = (msdVoltage * 10) / (3.3 - msdVoltage);
  Temp = (1 / ((1 / 298.15) + ((log(R / 10)) / 3950)));
  Temp = Temp - 278.15; // Converting kelvin to C
  skinTemp = Temp;
  mains = digitalRead(mainsRead);
  if (mains)
    digitalWrite(powerChanger, LOW);
  else
    digitalWrite(powerChanger, HIGH);

  //Logic Control
  if (controlMode)
  { //Temperature control
    if (airTemp < 38)
    {
      digitalWrite(Heater, HIGH);
      Alarm = 1;
      heaterTm = 1;
    }
    else
    {
      if (heaterTm == 1)
        delay(1000);
      heaterTm = 0;
      digitalWrite(Heater, LOW);
      Alarm = 0;
    }
  }
  else
  {
    if (skinTemp < 36)
    {
      digitalWrite(Heater, HIGH);
      Alarm = 1;
    }
    else
    {
```

```
        if (heaterTm == 1)
            delay(1000);
        heaterTm = 0;
        digitalWrite(Heater, LOW);
        Alarm = 0;
    }
}
if (Hum < 50)
{ //Humidity control
    digitalWrite(Humidifier, HIGH);
    Alarm = 2;
    humidTm = 1;
}
else
{
    if (humidTm == 1)
        delay(1000);
    humidTm = 0;
    digitalWrite(Humidifier, LOW);
    if (Alarm == 0)
        Alarm = 0;
}
if (airQuality < 100)
{ //Oxygen valve control
    digitalWrite(oValve, HIGH);
    Alarm = 3;
    oxygenTm = 1;
}
else
{
    if (oxygenTm == 1)
        delay(1000);
    oxygenTm = 0;
    digitalWrite(oValve, LOW);
    if (Alarm == 0)
        Alarm = 0;
}
if (Bpm > 90 || Bpm < 90 || SPO2 < 70)
    Alarm = 4;
else
{
    if (Alarm == 0)
        Alarm = 0;
}
if (AlarmON)
{
    digitalWrite(Buzzer, Alarm);
    if (sms)
        SendSms("HELLO , PATIENT NEEDS ATTENTION");
    sms = false;
}
else
```

```
  {
    digitalWrite(Buzzer, LOW);
    sms = true;
  }

  //SEND DATA to display
  if (millis() - tsLastReport2 > dataLog)
  {
    Msg = String(SPO2) + "$" + String(Bpm) + "$" + String(Hum) + "$" +
String(airQuality) + "$" +     String(airTemp, 1) + "$" + String(skinTemp, 1) + "$" +
String(Lux) + "$";
    Wire.beginTransmission(4);
    Wire.print(Msg);
    Wire.endTransmission();
    tsLastReport2 = millis();
  }

}

void Beep()
{
  digitalWrite(Alarm, HIGH);
  delay(70);
  digitalWrite(Alarm, LOW);
  delay(70);
}

void SendSms(String message)
{
  Serial.println("AT+CMGF=1"); //To send SMS in Text Mode
  delay(100);
  Serial.println("AT+CMGS=\"+255659838298\"\r");
  delay(100);
  Serial.print("Dear Sir/Madam!");
  Serial.println(message);
  delay(300);
  Serial.println((char)26); //the stopping character
  delay(300);
} //SMS

void SendtoServer(float SPO2, float Bpm, float Hum, float airQuality, float airTemp, float
skinTemp, float Lux)
{
//  Serial.println("SendtoServer\n");
  HTTPClient http;
  String postData;
  postData = "SPO2=" + String(SPO2) + "&Bpm=" + String(Bpm) + "&Hum=" +
           String(Hum) + "&airQuality=" + String(airQuality) + "&airTemp=" +
           String(airTemp) + "&skinTemp=" + String(skinTemp) + "&Lux=" + String(Lux);
  http.begin(client, "http://192.168.43.93/danny/punch.php");
  http.addHeader("Content-Type", "application/x-www-form-urlencoded");
  int httpCode = http.POST(postData);
```

```
    String payload = http.getString();
    Serial.println(payload);
    http.end();
}
```

Sample of codes used for web development

```
<?php

include '../inc/functions.php';
sec_session_start();
include '../inc/database.php';
define('ilyushin', true);
$pdo = Database::connect();
$pdo->setAttribute(PDO::ATTR_ERRMODE, PDO::ERRMODE_EXCEPTION);
// print_r($_SESSION);
ini_set('display_errors', 1);
ini_set('display_startup_errors', 1);
error_reporting(E_ALL);
if (login_check($pdo) == true) {
  // echo "true";
  if (isset($_SESSION['level']) && $_SESSION['level'] == 777) {  ?>

    <!DOCTYPE html>
    <html lang="en">

    <head>
      <link rel="stylesheet" href="../inc/material-icons.css">
      <link rel="stylesheet" href="../inc/materialize.min.css">
      <link rel="stylesheet" href="../inc/gold.css">
      <link rel="stylesheet" href="../inc/babylon.css">
      <meta name="viewport" content="width=device-width, initial-scale=1.0" />
      <link rel="shortcut icon" href="../inc/img/logo4b.ico" type="image/x-icon">
      <title>Boblabs Project Management System</title>
    </head>
    <style>
      canvas {
        /* border: 4px solid rgb(163,230,241); */
        border-radius: 8px;
      }

      .chart-container {
        position: relative;
        margin: auto;
        height: auto;
        width: 90%;
      }
      .act7 {
        margin-top: -15px;
        padding-bottom: 20px;
      }
      .card-header2 {
        left: 0%;
        top: calc(-100px/3);
        right: 50%;
        /* box-shadow: 0 4px 20px 0px rgba(0, 0, 0, 0.14), 0 7px 10px -5px rgba(255, 152,
0, 0.4); */
        border-radius: 5px;
```

```
    height: 330px;
    width: 96%;
}

.card-header3 {
    left: 0%;
    top: calc(-100px/4);
    right: 50%;
    /* box-shadow: 0 4px 20px 0px rgba(0, 0, 0, 0.14), 0 7px 10px -5px rgba(255, 152,
0, 0.4); */
    border-radius: 6px !important;
    height: 60px;
    width: 96%;
}

.card-header3 h5 {
    padding-top: 15px;
}

.vcc {
    top: -22px;
}

.bgg {
    background: rgb(198, 199, 206);
    border-radius: 8px;
}

tr {
    border-bottom: 1px solid rgba(0, 0, 0, 0) !important;
}

table.striped>tbody>tr:nth-child(odd) {
    background-color: rgba(0, 0, 0, 0.05);
}

.cont {
    width: 98%;
    margin-left: 1%;
    margin-right: 1%;
}

.td-actions {
    display: -webkit-box;
    display: -ms-flexbox;
    display: flex;
}

.dark-edition .btn.btn-white.btn-link {
    background-color: transparent;
    color: #fff;
    box-shadow: none;
```

```
}

.btn.btn-white {
    color: #9095a2;
    background-color: transparent;
    border-color: transparent;
}

a.btn {
    -webkit-box-shadow: none !important;
    box-shadow: none !important;
    padding: 0 8px;
}

.toast {
    background-color: transparent;
    padding: 0;
    line-height: 0.2em;
    box-shadow: none;
}

.dropdown-content li>span {
    padding: 6px 16px;
    text-align: center;
}
    p,
    label {
        font-size: 12px !important;
    }

    .my-box {
        padding: 8px !important;
    }

    .input-field {
        margin-bottom: 0 !important;
        margin-top: .7rem !important;
    }

.select-wrapper input.select-dropdown {
    color: white !important;
}
  <input type="text" id="fullname" name="fullname" class="validate grad-text" required>
                                        <label style="left:0" for="fullname">Full Name</label>
                                    </div>
                                    <div class="input-field a col s12 m12">
                                        <i class="material-icons prefix grad-
text">person_pin</i>
                                        <input type="text" id="mother_name"
name="mother_name" class="validate grad-text" required>
                                        <label style="left:0"
for="mother_name">UserName</label>
```

```
                                        </div>
                                        <div class="input-field a col s12 m12">
                                            <i class="material-icons prefix grad-text">wc</i>
                                            <select id="gender" name="category" class="white-
text">
                                                <option value="Admin" selected>Admin</option>
                                                <option value="Super_admin">Super
Admin</option>
                                            <i class="material-icons prefix grad-text">face</i>
                                            <input type="password" id="passcode"
name="passcode" class="validate grad-text" value="123456" required readonly>
                                            <label style="left:0" for="passcode">Default
Password</label>
                                        </div>

                                        <div class="center">
                                            <button class="btn login hoverable blue-grey center"
type="submit" name="Submit" style="background: grad;height: 30px;line-height:
25px;border-radius: 3px; margin-top: 10px">Registter
                                                <i class="material-icons right">send</i>
                                            </button>
                                        </div>
                                    </form>
                                    <div class="" style="margin-top: 10px;"></div>
                                </div>

                            <div class="divider" style=" height: 4px;  background-color:
#607d8b; margin-top: -1px; margin-bottom: 16px;"></div>
                        </div>
                        <div style="clear: both;">
                            <a href="users.php" class="btn-flat blue-grey white-text"
style="text-transform: none; height: 25px; line-height: 26px; background-color: rgba(0, 0, 0,
0.05);">
                                <i class="material-icons">remove_red_eye</i>
                            </a>
                        </div>

                        <!-- Model add incubator -->
                        <div id="modal_addincubator" class="modal">
                            <div class="modal-content">
                                <div class="my-box bg-log001 white-text  hoverable z-depth-1 "
id="">
                                    <div class="" id="">
                                        <h5 class="center black-text" style="font-weight: 500;
margin-top: 20px">

                                        <div class="input-field a col s12 m12">
                                            <i class="material-icons prefix grad-
text">person_pin</i>
                                            <input type="text" id="inc_number"
name="inc_number" class="validate grad-text" required>
```

```
                                        <label style="left:0" for="inc_number">Incubator
Number</label>
                                    </div>
                                    <input type="hidden" name="registrar" value="<?php
echo ($_SESSION['user_name']); ?>">

                                    <div class="center">
                                        <button class="btn login hoverable blue-grey center"
type="submit" name="Submit" style="background: grad;height: 30px;line-height:
25px;border-radius: 3px; margin-top: 10px">Register
                                            <i class="material-icons right">send</i>
                                        </button>
                                    </div>
                                </form>
                                <div class="" style="margin-top: 10px;"></div>
                            </div>
                        </div>
                    </div>
                </div>

            </div>
        </div>
    </div>
    </div>
    </div>
</div>

    $(document).ready(function() {
        $('.modal').modal();
    });

    $('.dropdown-trigger').dropdown();

    $(document).ready(function() {
        $('.sidenav').sidenav();
    });

    $(document).ready(function() {
        $('.tooltipped').tooltip();
    });

    document.addEventListener('DOMContentLoaded', function() {
        var elems = document.querySelectorAll('select');
        var instances = M.FormSelect.init(elems, "");
    });
</script>
</body>
</html>
<?php
  } else {
    header('Location: ../');
  }} else {
```

```
    header('Location: ../');
}
```

POSTER PRESENTATION

DEVELOPMENT OF A LOW COST IoT-BASED INFANT INCUBATOR IN TANZANIA.CASE STUDY EAST AFRICA

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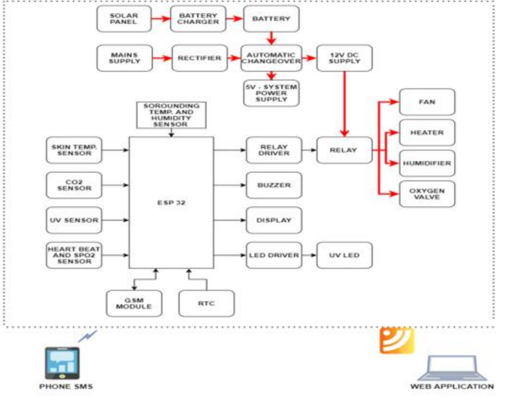
Introduction

Every year, an estimated four million babies die around the world, with the great majority of deaths taking place in underdeveloped countries. In addition, yearly one million neonates die in Sub-Saharan Africa with half of these deaths occurring within the first seven days of life. in Tanzania, a neonatal mortality rate is estimated to 21 per 1,000 live with births birth asphyxia, preterm birth problem and infections such as sepsis and meningitis been among the most causing factors of this death. According to literature, the use of science and technology has improved neonatal care resulting in increasing survival rates. The majority of infants require special care after birth due to a variety of health complications caused by a variety of reasons and are admitted to the neonatal intensive care unit were they are provided with conducive environment to aid there growth.

Methodology

Since the system is not new and major requirements are well known, the agile model particularly the scrum agile model was adopted mainly because system development and testing processes can be conducted in parallel hence speeding up the project to meet the required deliverable

The system block diagram

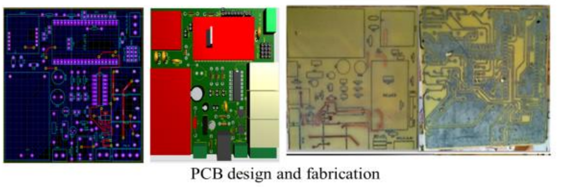


System Functional Units

- Processing unit
- Sensing unit
- Power supply
- Web page
- Actuating unit
- Display and alert

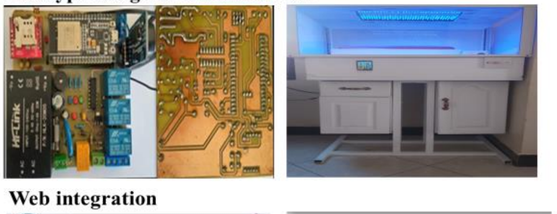
Developed solution

The goal of this project is to develop a low cost infant incubator that ensures the safety of premature and neonates born with complications by offering efficient and effective environment and care to aid their growth.

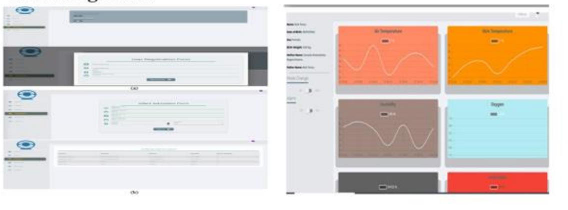


PCB design and fabrication

Prototype designed and the circuit



Web integration



Evaluation.

Significance:

- To reduce hospital costs in buying equipment, especially in a low-income setting
- To reduce the mortality rate in neonates due to asphyxia, hypothermia, and jaundice
- Knowingly the impact of ICT and web technology in the health sector the system will integrate all neonates' data into one web page for current and future uses making it easier to manage and track the neonate's particulars.