UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE)

THESIS TITLE:

DESIGN AND PROTOTYPE OF IMPROVED VACCINE MONITORING SYSTEM

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A Dissertation Submitted to the Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE), University of Rwanda as partial fulfilment of the requirements for the Master's Degree in Biomedical Engineering.

Supervised by:

Dr. UWISENGEYIMANA Jean de Dieu and Dr. SIBOMANA Louis

DECLARATION

I, **MUNYARUYANGE Faustin**, declare that this dissertation entitled "Design and prototype of Improved Vaccine Monitoring System" is my original work based on research and prototype and has not been submitted for any other degree or professional qualification.

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CERTIFICATE

This is to certify that the project entitled “Design and prototype of Improved Vaccines Monitoring System” is a record of original work done by **MUNYARUYANGE Faustin**, Reference number: **221000402**, a Msc. Degree student in Biomedical Engineering.

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May the lord reward you all.

ABSTRACT

The most reliable method of obtaining immunity against numerous diseases that might be fatal is through vaccination. Due to improper cold room management, vaccine safety is, however, highly limited in developing and underdeveloped nations. The design and development of an improved cold room monitoring system for the ongoing surveillance of vaccine inventories is presented in this study. Most of hospitals use manual temperature recording by using a refrigerator’s built-in thermometer without the monitoring of the closure and opening of the cold room. This approach consists of a unique feature that manages individual vaccine stores in addition to the power monitoring, temperature, humidity levels and closing and opening of the cold room. Additionally, both system's hardware and software monitor the graphic changes in temperature in the cold room in real time. This proposed approach has the potential to be incredibly effective at minimizing vaccine waste. This is due to the suggested system's ability to remotely monitor the entire procedure and ensure the safety and vaccination usage rate by sending an e-mail whenever the cold room is opened.

Keywords: Vaccines, cold room, Microcontroller, web application.

LIST OF ACRONYMS

CEBE: Centre of Excellence in Biomedical Engineering and E-health

CSS: Cascade style sheet

EMAIL: Electronic mail

HDT: Temperature and humidity sensor

HTML: Hypertext mark-up language

HTTP: Hypertext transfer protocol

I/O: Input / Output

IDE: Integrated development environment

IRB: Institutional review board.

LCD: Liquid crystal display

MCU: Microcontroller unit

MoH: Ministry of Health

MYSQL: my structured query language

NIP: national immunization program

PHP: Hypertext processor

POST**:** Power On Self-Test

PQS: Performance quality safety

RBC: Rwanda Biomedical Center

SDGs : Sustainable development goals

SMS: Short Message Service

TCP/IP: Transmission control protocol/internet protocol

UR: University of Rwanda

WEBAPP: Website application

WHO: World Health Organization

WI-FI: Wireless fidelity

WSN: Wireless sensor network

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CHAPTER 1. GENERAL INTRODUCTION

1.1 Introduction

The sustainable way of fighting against pandemics in general is the usage of vaccination. Vaccines save the lives of around 2.5 million children every year around the world [1] . Vaccines must be continuously stored in a limited temperature range from $+2^0$c up to $+8^0$c as recommended by WHO from the time they are manufactured until the moment of vaccination. The high temperature or low temperature can cause them to lose their potencies. Proper vaccine storage and handling are important factors in preventing and eradicating many common vaccine preventable diseases. Yet, each year, storage and handling errors result in re-vaccination of many patients and significant financial loss due to wasted vaccines[2]. Failure to restore and handle vaccines properly can reduce vaccine potency, resulting in inadequate immune responses in patients and poor protection against disease. Patients can also lose confidence in vaccines and providers if they require re-vaccination because the vaccines they received may have been compromised. According to the World Health Organization (WHO), increasing vaccination coverage might avert an additional 1.5 million deaths per year. An adverse heat event, according to WHO regulations, occurs when vaccinations are exposed to temperatures exceeding 8°C for a duration of 10 hours or more [3]. The improved vaccines monitoring system shall provide a good way to monitor the status of temperature, humidity, power and the opening and closure of the cold room. The collected information is stored to the cloud platform where the staff can monitor the vaccines status.

1.2. Vaccines Sensitivity

All vaccines are sensitive to extreme heat and extreme cold and require both proper vaccine storage and management to avoid any loss of potency[4]. Vaccine sensitivity to heat the recommended range is +2 degrees Celsius up to +8 degrees Celsius and freeze -25 degrees Celsius up to -15 degree Celsius [4].

Table 1.1 Lists of vaccines temperature sensitivity from least to most sensitive.

Vaccines	freezing	VACCINES	Heating
Varicella-zoster virus		Typhoid ps	Least sensitive
Rubella		Rabies	
Rabies	Least sensitive	Pneumococcal (polysaccharide-protein conjugate)	
Oral poliovirus		Meningitis C (polysaccharide-protein conjugate)	
Measles, mumps, rubella		Meningitis A (polysaccharide-protein conjugate)	
Measles		Hib (freeze dried)	
Japanese encephalitis (live and inactivated)		Hepatitis B	
Hib (freeze dried)		Hepatitis A	
Bacillus Calmette-Guérin		T, DT, dT	
Yellow fever		Japanese encephalitis (inactivated)	
Rotavirus (liquid and freeze dried)		Human papillomavirus	
Meningitis A (polysaccharide-protein conjugate)		Bacillus Calmette-Guérin	
Typhoid PS		Yellow fever	
Inactivated poliovirus		Rubella	
Hib (liquid)		Rotavirus (liquid and freeze dried)	
Influenza (inactivated, split)			

Cholera (inactivated) T, DT, dT Pneumococcal (polysaccharide-protein conjugate) Meningitis C (polysaccharide-protein conjugate) Human papillomavirus Hepatitis B Hepatitis A DTwP-hepatitis B-Hib (pentavalent) DTwP DTaP-hepatitis B-Hib-IPV (hexavalent) DTaP	Most sensitive	Measles Hib (liquid) DTwP-hepatitis B-Hib (pentavalent) DTaP-hepatitis B-Hib-IPV (hexavalent) DTwP DTaP Cholera (inactivated) Measles, mumps, rubella Japanese encephalitis (live) Inactivated poliovirus Influenza (inactivated, split) Varicella-zoster virus Oral poliovirus	Most sensitive

1.2 Problem statement

Most of ddeveloping and low income countries get vaccinations through government long term loans and donations. Vaccines must be continuously stored in a limited temperature range from the time they are manufactured until the moment of vaccination; the high temperature or low temperature can cause them to lose their potencies. Currently vaccines monitoring is done by using manual or traditional system without a remotely tracking system of opening and closure, power outage temperature and humidity of the cold room and expensive monitoring systems purchased from foreign countries. In developing and low income countries vaccines are misused and wasted at the storage site before they are used which brings into consideration to the overall tracking system of cold room opening and closure, power outage, temperature and humidity. The previous research discussed the monitoring system of vaccine stores temperature and humidity, power outage without the remote tracking system to monitor the closure and opening of cold room[2].The creation of a WSN based on health-care monitoring, which has been used in the health-care process and has made a significant contribution in recent years, And it was the most problem-solving research, such as using sensors to interpret data, which gives the current status of health and sends emergency messages to a distant server[5]. In this research project, we propose an improved vaccine monitoring system with unique feature of managing individual vaccine store in addition to the power monitoring, temperature, humidity levels and closing and opening the cold room. Additionally, both the system's hardware and software monitor the graphic changes in temperature and humidity in the cold room in real time. This proposed approach is affordable and has the potential to be incredibly effective at minimizing wasted vaccines. This is due to the suggested system's ability to remotely monitor the entire procedure and provide an e-mail notification to the vaccines operator whenever the cold room is opened or temperature excludes the set range.

1.3 Research Questions

The following questions are the main questions which guided this study:

- ❖ How vaccines are monitored in healthcare services?
- ❖ Is there any system that can facilitate the monitoring and management of vaccines?
- ❖ Does the system provide all needed information to facilitate the monitoring and managements of vaccines?

1.4 Objectives

1.4.1 General Objective

The general objective is to design and develop an improved vaccine monitoring system.

1.4.2 Specific Objectives

- To understand the features of the current existing monitoring system and its affordability.
- To design and develop a prototype for improved system for monitoring vaccines, cold room power outage, temperature and humidity, closure and opening.
- To test the developed prototype for ensuring if it provides the solution to the identified challenges.

1.5 Study Scope

This study focused on the design and implementation for an improved vaccines monitoring system which is affordable for hospitals. The system can be used in healthcare services to provide the best way of monitoring vaccines temperature, humidity and opening of the cold room as well. Vaccines potency is kept as long as the monitoring of graphical changes in temperature and humidity is done remotely. Apart from this the system shall also monitor and alert the opening of the kit for accurate management of vaccines. Though this work was successfully done, the sample taken was not large enough due to the tardily delivering of IRB and research feels by the university thus many hospitals delaying in providing data collection acceptance. The data collection was conducted in the nearest hospitals.

1.6 Significance of the study

In Rwanda, the created system will be utilized to monitor the vaccines that are temperature-sensitive. It will assist in determining the status of the cold room, where several sensitive parameters must be tracked in real time, and notify the appropriate parties whenever the cold room's fixed temperature and humidity values deviate from the norm.

By using a door sensor to detect the closing and opening of the cold room and sending an email warning, this system will offer better cold room monitoring. The liquid crystal display will show every aspect of the cold room's state. The dashboard must show every iteration of both parameters graphically.

1.6 Organization

This thesis report is divided into five chapters. The project's overall introduction is covered in the first chapter. The second chapter provides a quick overview of related studies. The third chapter outlines the various methodologies that were employed to conduct the study. Information regarding the system design, prototypingg, simulation results and their analysis are covered the fourth chapter. In the final chapter, recommendations for the nation and conclusion are explored.

CHAPTER 2. LITERATURE REVIEW

The brief literature review of relevant studies is covered in this chapter. This comprises the issue that was looked at by earlier researchers, the technical solution that was suggested, the methodology approach used, and the findings. After some time, the gaps in the prior similar and related studies were discovered, and these serve as both the justification and the driving force of the current investigation.

2.1 Historical Background

Over 2000 years ago, it was found that smallpox vaccination was done in China and India, Edward Jenner, a British surgeon, was credited with introducing the modern notion of vaccination[6]. In 1796, Edward Jenner inoculated patients with pustules from cowpox[6] . Vaccination is one of humanity's greatest public health achievements. When used correctly, vaccines used in national immunization programs (NIPs) are deemed safe and effective[7]. Vaccines, on the other hand, are not without danger, and unpleasant reactions do occur infrequently after vaccination. The success of immunization programs depends on public trust in vaccine safety. Vaccines save the lives of around 2.5 million children every year around the world [8]. According to WHO, Immunization is one of the most effective and affordable health therapies available [9]. Every year, it saves millions of lives by preventing terrible sickness and incapacity[10]. It's also crucial for reaching the Sustainable Development Goals (SDGs), which were set out by world leaders in 2016 as a way to alleviate poverty and increase human development [11]. Innovative ways are being found to distribute and administer vaccines and to improve immunization services. Digital tools, new, needle-free techniques for vaccine administration and more robust vaccine storage and supply chains promise to transform immunization programs over the next decade[11].Vaccines are very important in promoting health as they assist healthy people in maintaining their health, removing a major roadblock to human progress.

Vaccines are time and temperature sensitive products and they are all affected by heat, some by freezing, and some by light, and thus they must be stored and transported at specific temperatures[3]. Temperature monitoring of vaccine storage has always been and will continue to be an important part of the vaccine cold chain. The user can avoid temperature excursions outside the permitted limits by monitoring the temperature of cooling equipment [12]. According to the World Health Organization (WHO), increasing vaccination coverage might avert an additional 1.5 million deaths per year[13]. An adverse heat event, according to WHO regulations, occurs when vaccinations are exposed to temperatures exceeding 8°C for duration of 10 hours or more[5] . The World Health Organization (WHO) recommends temperature monitoring systems that take measurements and store records, as well as keeping vaccinations and comparable medicinal goods within a particular temperature range, to protect public health [14]. Vaccines have more rigorous refrigeration requirements than many foods and medications because they contain biological components that are permanently destroyed if frozen [15]. Temperature monitoring devices are recommended by the WHO based on the unique cold chain equipment application and monitoring purpose[12]. The Performance, Quality, and Safety (PQS) criteria and verification processes established by the World Health Organization (WHO) establish basic technical and usability standards for these devices[8].

Vaccines must be kept in a temperature-controlled environment until they are given to patients 2°C to 8°C for most vaccines[5]. It is critical to keep medical cold storage rooms at the right temperature. The pharmaceuticals or vaccines kept in medical freezers will be harmed if the temperature isn't right [3]. Temperature monitoring that is accurate and well-managed is critical for ensuring vaccine quality throughout the supply chain and reducing vaccine waste due to heat or freezing [1]. Pandemics have afflicted the world for a long time, including Rwanda. Currently. The use of vaccination is a long-term strategy for combating pandemics in general. More vaccinations lose their ability to protect against disease in stores due to lack of improved monitoring system and expensive vaccines monitoring systems. This is more common in developing and impoverished countries.

To resolve this issue, the design and development of inexpensive vaccine monitoring system for power outage, temperature and humidity, closure and opening of the cold room will provide a good way to monitor the status of temperature, humidity, power, closure and opening of cold room. Once the cold room is opened the system sends an email. The collected information shall be sent to the cloud platform which helps the staff to continuously observe the graphical changes of the temperature and humidity on dashboard.

2.2 Related works

According to D. Mahesh Kumar created a WSN based on health-care monitoring, which has been used in the health-care process and has made a significant contribution in recent years was created. And it was the most problem-solving research, such as using sensors to interpret data, which gives the current status of health and sends emergency messages to a distant server [15].

According to Raisa Tahseen Hasanato , An IoT based Real-time Data-centric Monitoring System for Vaccine Cold Chain monitoring system for the continuous monitoring of the vaccine distribution and transportation process was developed[2].

According to UR students, Kalisa jean bosco and Tuyisenge Jean claude the development of an Internet of Things Remote Monitoring Solution (IoT RMS) to provide a real-time monitoring of storage and delivery of these temperature-sensitive vaccines together with the ability to alert whenever there is an issue[13].

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Overview

This research endeavor has been carried out using a variety of methods. An improved vaccines monitoring system that took into account the requirements of the people who were directly involved in cold room monitoring. This method, which is based on design thinking, helped create a practical solution that can address problems like vaccines usage rate and user interaction patterns. This study employed the procedures and techniques listed below.

3.2 Research Process

During this stage, data were gathered from cool room technicians via questionnaires. The criteria and technical specifications that guided the construction of the monitoring system solution were determined after a thorough analysis of the data amassed up to this time. During this study, we were able to learn enough about the use of the current cold room monitoring systems, their challenges, and the modifications they need. After data analysis the design and development of a system that addresses all the issues faced by the existing system was initiated. Outlining system requirements, technical requirements and system design. The prototype was developed and tested to ensure if it really respond to the issues.

3.3 Review and analysis of the technical and design requirements beforehand

Through questionnaires, we collected information from cool room technicians during this phase. A thorough study of the data gathered at this point led to the demands and technical requirements that informed the design and development of an improved vaccines monitoring system that responds to the challenges faced by vaccines operators in their daily works and give them freedom to work on other healthcare services.

3.3.1 Research Design Method

This study concentrated on gathering quantitative information. Questions on the method used to monitor vaccines, opening detection of the cold room, WHO recommended temperature range, power outage detection, mode of notification in any abnormal case and various challenges they face on a daily basis were prepared and revised to ensure that they are good enough to help us get the information we needed from cold room technicians. The fact that the study surveys were anonymous allowed respondents to submit truthful information.

3.3.2 Research population

This research was targeting cold room technicians from Hospitals. five hospitals were used in this research. Kacyiru hospital, University teaching hospital of Kigali , Muhima district hospital, Remera rukoma hospital and Kibagabaga district hospital. At the hospital, cold room for vaccine storage are under the control of the vaccine operators, these operators are permanent workers and their duties includes following up on the vaccines from the time they are received and keeping them safe from losing their potency. There were at least two cold room operators in each hospital.

3.3.3 Samples taken

Ten respondents from five hospitals were used to gather the required information. The appropriate cold room technicians were selected to answer the questionnaires of five questions regarding vaccines monitoring systems. The selection of such a sample was based on the difficulties encountered during this phase of data collection, which were mostly brought by University's delaying in providing the Institutional review board and research feels which has lead us to collect data in the nearest hospitals.

3.3.4 Data Evaluation

The respondents' knowledge of the methods for monitoring vaccine temperature, the recommended temperature range, the monitoring of cold room openings, the alerting procedures for abnormal situations, and their understanding of the power situation at the storage supply were evaluated using five different questions. Each question had a Yes/No choice.

3.4 Gap Identification

Referring to the questions asked and answers from ten respondents in five hospitals the results clearly indicates that there is a big gap regarding vaccines monitoring system especially in monitoring the opening and closing of the cold room. 100 percent cannot monitor vaccines usage rates 80 percent of hospitals use traditional method for daily basis recording system and. I also discovered that the freezers used to store vaccines have built-in thermometers with displays that show the current temperature, and cold room workers must continuously check the displays to note any potential abnormal temperature changes.

3.5 The prototype system's development and design.

After identifying and evaluating the needs of cold room technicians, we set out to design and develop a prototype system, in which both the logical and physical elements necessary for the system's efficient operation were modeled, simulated, and tested in order to create a comprehensive monitoring system that addresses the problems they face.

3.5.1 System block diagram

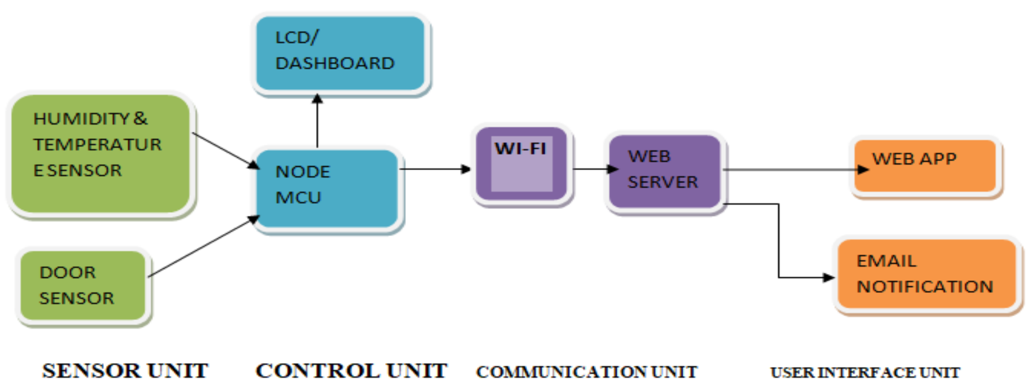

Figure 3.1. The block diagram of improved vaccines monitoring system

The block diagram in figure 3.1 shows the various steps from temperature collection to data display, which is done using a web application. The DHT11 sensor was used to record temperature and humidity, and the door sensor to detect the opening and closing of the cold chamber. Wi-Fi is used for data transmission to the server and the user interface web application that permits the user to view and track the temperature recorded. The refrigerator has a liquid crystal display (LCD) mounted on it that shows the humidity and temperature readings within the cold area as well as the door status.

The prototype design for this research project consists of a variety of hardware and software elements, however this chapter gives an overview of the system architecture prototyped for this study. It provides information on system development and implementation prototypes for the storage of vaccinations in a chosen location. four structures are present in the architecture of the prototype for the improved vaccinations monitoring system. These consist of control unit structure, the database structure, user interface, and wireless communication structure. The prototype design model block diagram is described in the paragraphs that follow.

3.5.2 System flow chart

The system flow chart below describes the functionality of the system from the sensors, how decisions are taken and feedback.

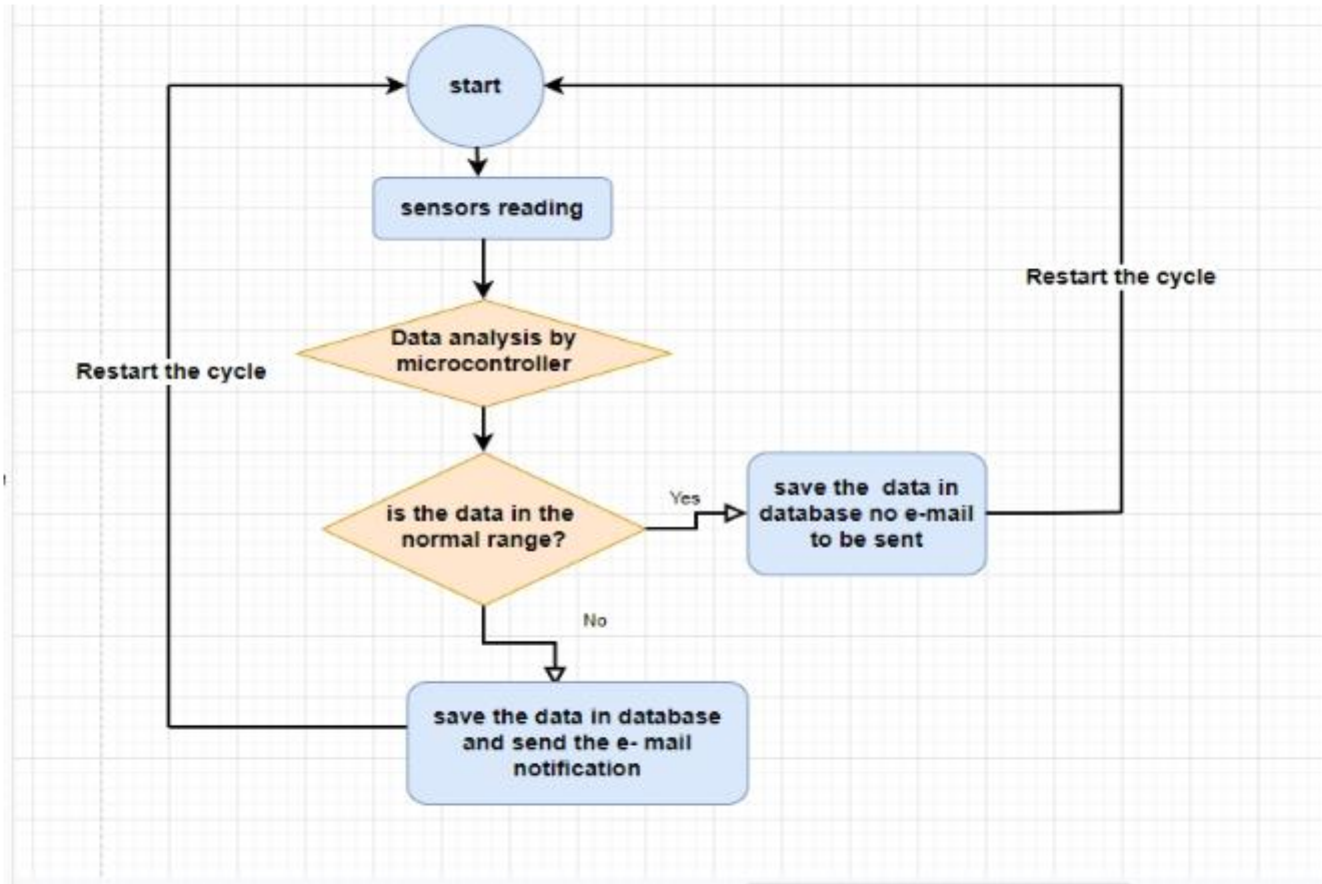

Figure 3.2 The system flow chart

The figure 3.2 shows the flow chart that describes the whole process. from sensors to the email notification sent after data analysis by the system. The sensors send the readings to the microcontroller which is connected to Wi-Fi that helps it to transfer data to the web server for storage. the microcontroller is connected to the dash board for splaying the readings. Once the value deviated from the range the system sends a notification email to the technician and corrective measure can take place immediately.

3.6 Checking the cold room monitoring system That was designed.

The accuracy and connection of the developed improved vaccinations monitoring system was evaluated. Data were obtained, including comparative testing to find out which sensors will work best in the end product in terms of accuracy and robustness.

3.7 Sensing structure

The real-time monitoring of temperature and humidity and opening of vaccine stockpiles is the primary objective of this improved vaccine monitoring system for temperature-sensitive vaccines. Most vaccines are maintained in freezers and refrigerators. sensors for temperature and humidity and door sensor are used.

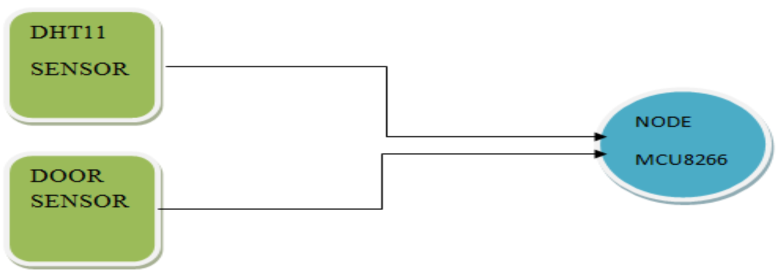

Figure 3.3 The temperature, humidity, and door smart sensor connections to the microcontroller.

The temperature, humidity, and door smart sensor connections to the microcontroller are shown in the figure 3.3.

A sensor is a type of electronic component that detects events or changes in its environment and conveys the information to other electronic components, most frequently a computer processor. Always used in conjunction with other electronic equipment are sensors. The Digital Temperature and Humidity Sensor (DHT11) was utilized to measure the daily temperature inside the freezers for our system prototype.

The figure 3.4 depicts the temperature-humidity utilized for system prototyping.

Figure 3.4 Temperature and humidity sensor DHT11

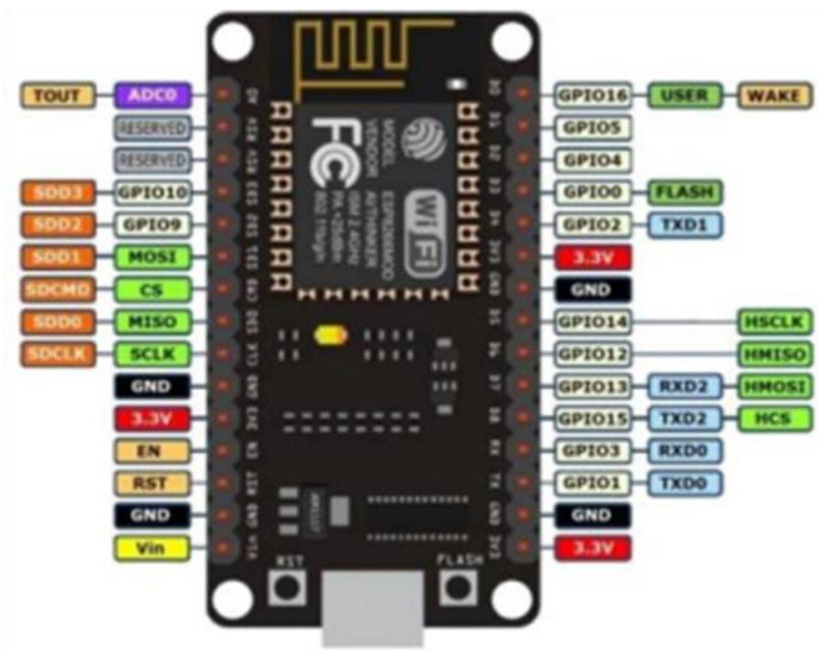

Figure 3.5 Microcontroller unit Node MCU8266

DHT11 and a door sensor were immediately interfaced with a microcontroller to gather the sensed temperature in vaccine storage (Node MCU ESP8266). A self-contained SOC with an integrated TCP/IP protocol stack, the ESP8266 Wi-Fi Module enables any microcontroller to connect to a Wi-Fi network, as seen in Figure 3.5. Either the ESP8266 can host an application or it can delegate all Wi-Fi networking tasks to a different application processor. Platform IO, a professional cross-platform, cross-architecture, multi-framework Integrated Development Environment (IDE) tool for embedded system and software engineers that build embedded applications, was used in the design of this board. Hardware programming can be done in a way that is more developer-friendly by leveraging Platform to offer a global IDE interface.

3.8 Wireless communication system.

Using various wireless or wired connection protocols, the technologies enable end users to access data gathered from the local cold room and real-time monitoring .data are transmitted to the created cloud platform utilizing the Hypertext Transfer Protocol (HTTP) using POST method after being collected from the site. As a client-server request-response protocol, HTTP is a widely used application protocol.

The temperature data from the DHT Sensor attached to the node MCU are delivered to the cloud database server during the system prototype's implementation using the HTTP client, which employs HTTP response and request to communicate with the web clients. The data saved in the database is retrieved using Hypertext Pre-processor (PHP), a popular open source general-purpose scripting language that is especially suited for online development and may be included into Hypertext Mark-up Language HTML.The dashboard was created in HTML and uses cascading style sheets (CSS) to achieve dynamic effects in web browsers using JavaScript, an object-oriented.

3.9 User interface structure

The user interface for the monitoring system cloud application, through which the user may see and monitor the temperature, was constructed using the programming languages Hypertext Mark-up Language and Cascading Style Sheet Web Applications. These data are transmitted from various sensor nodes and are then saved on an online server. The data were pulled from the MySQL database and pushed to the dashboard using PHP scripting language. Dashboard data retrieval and storage are shown in figure 3.6.

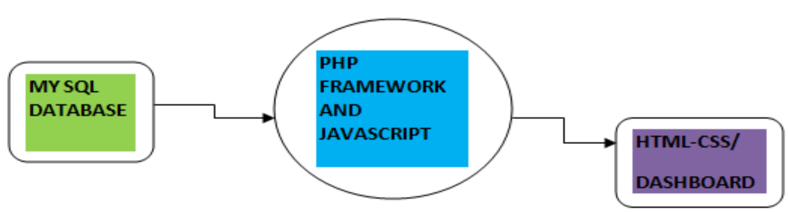

Figure 3.6 The user interface structure.

3.10 Database Structure.

Online servers with databases for storing the various data collected from various sensor nodes are required for the control of temperature monitoring systems from the cold room and their opening. Data is gathered and kept in many tables that make up a database because it needs to be controlled.

CHAPTER 4 THE PROJECT RESULTS AND IMPLEMENTATION.

4.1 Field analysis results

The responses from ten participants in five different hospitals obtained from five hospitals revealed that 80% of all respondents manually record vaccine temperatures on a daily basis, 0% of monitoring systems cannot detect the opening of the cold room, 60% were aware of the WHO-recommended temperature range of (2-8^{o}C), 20% can receive a notification about the status of the cold room, and 20% can also be aware of the power source outage.

Data analysis employed descriptive statistics. Additionally, I discovered that vaccination refrigerators include built-in thermometers with displays that show the current temperature. Cold chain operators must continuously monitor the displays to record any potential unexpected temperature changes.

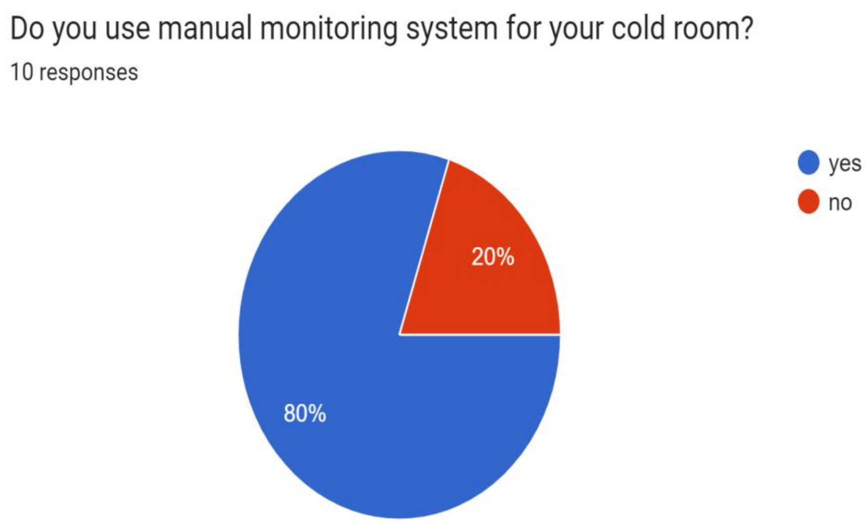

Figure 4.1 question 1 and answer from 10 respondents.

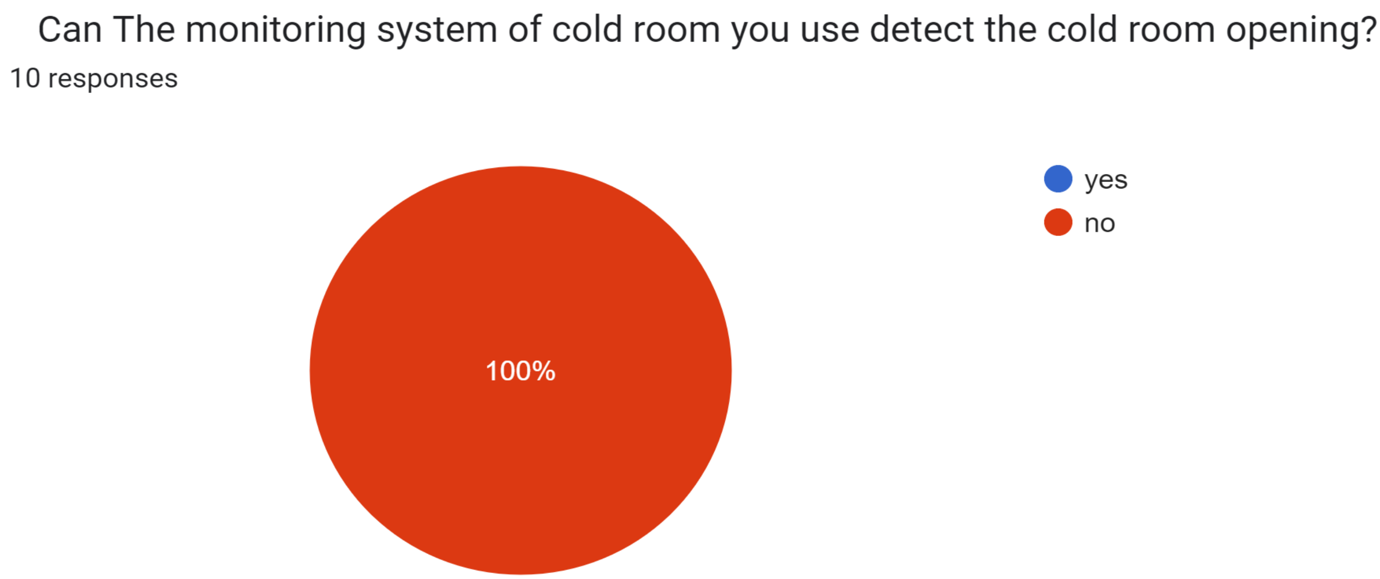

Figure 4.2 question 2 and answers from 10 respondents.

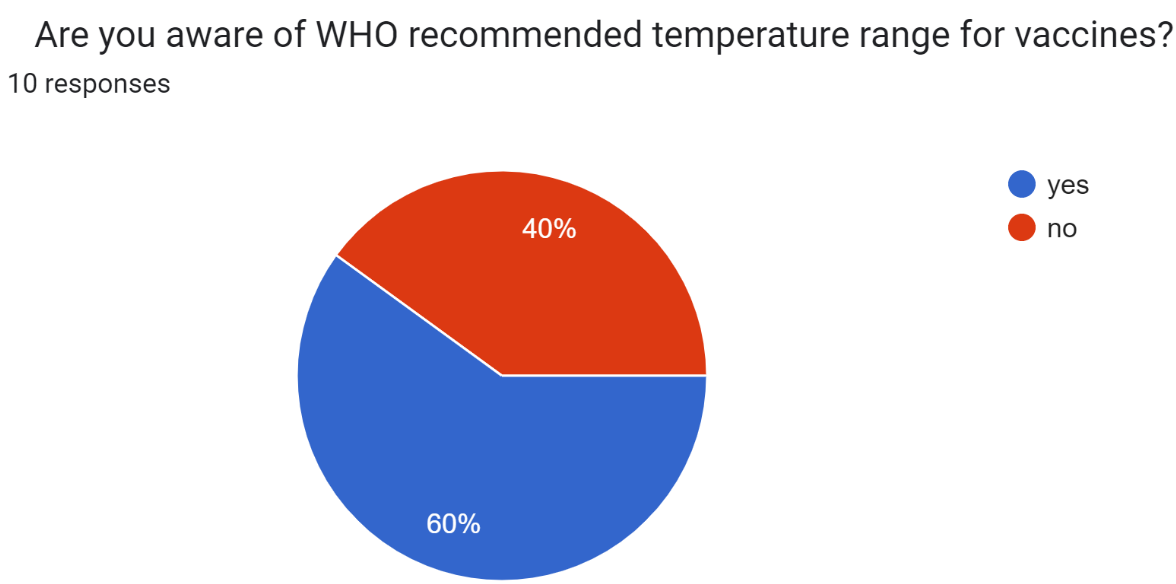

Figure 4.3 question 3 and answers from 10 respondents.

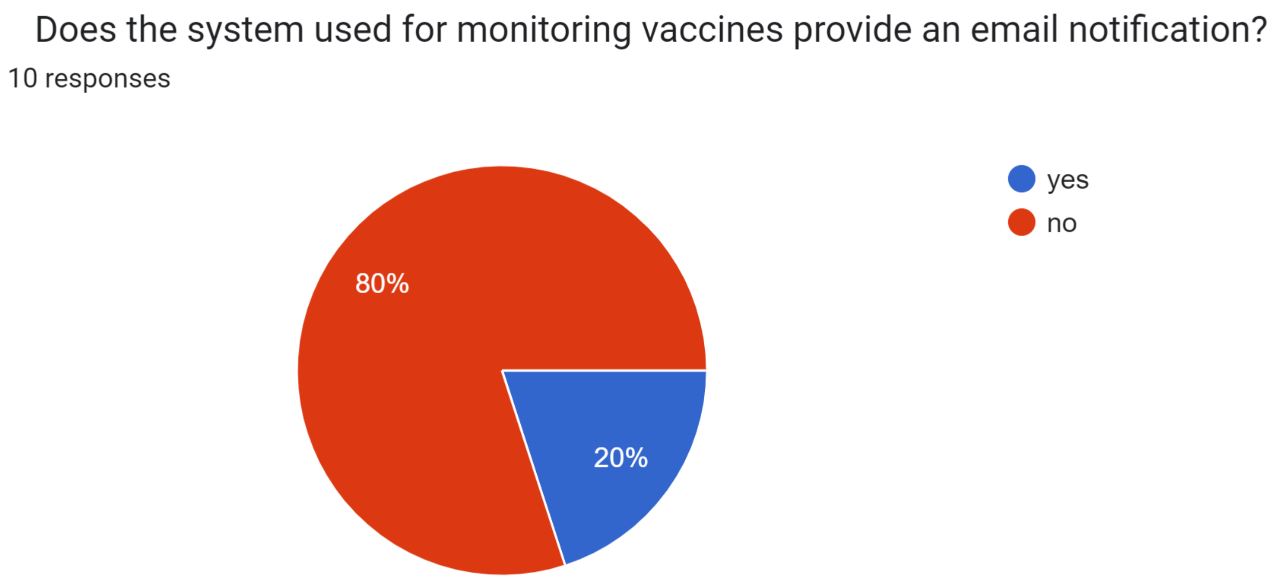

Figure 4.4 question 4 and answers from 10 respondents

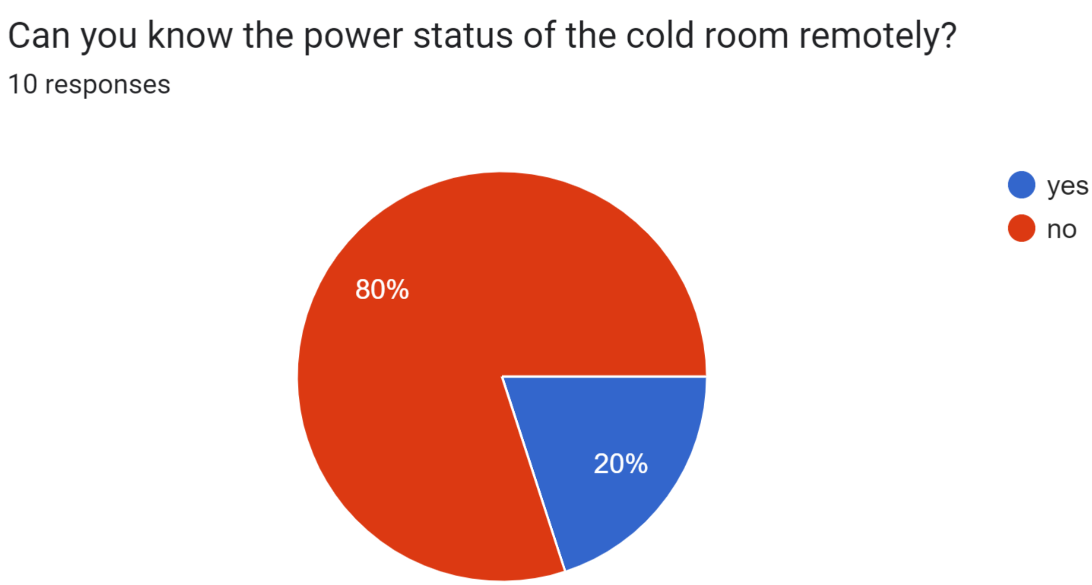

Figure 4.5 question 5 and answers from 10 respondents.

4.2 System design results

This part provides and discusses the anticipated outcomes of the upgraded vaccine monitoring system for effective storage in Rwanda. The graphs of temperature variations from the cold room where sensors are installed are also described, along with the findings from sensors to the user interface of the system during prototype implementation. I'm presenting the data from this prototype as I worked on storage. The prototype's outputs include the cold room's temperature, humidity, and opening, which are all tracked via a web application interface. The system also provides to the cold room technicians an email notification that indicates whether the cold room has been opened and whether the temperature and humidity have excluded the normal range.

4.2.1 User Interface Credentials.

The Figure 4.6 shows the primary dashboard of Rwanda's upgraded vaccine monitoring system for temperature-sensitive vaccine storage. It offers an interface page where each user may enter their login information to manage and monitor the temperature, humidity, and store opening when they open the domain name of the system.

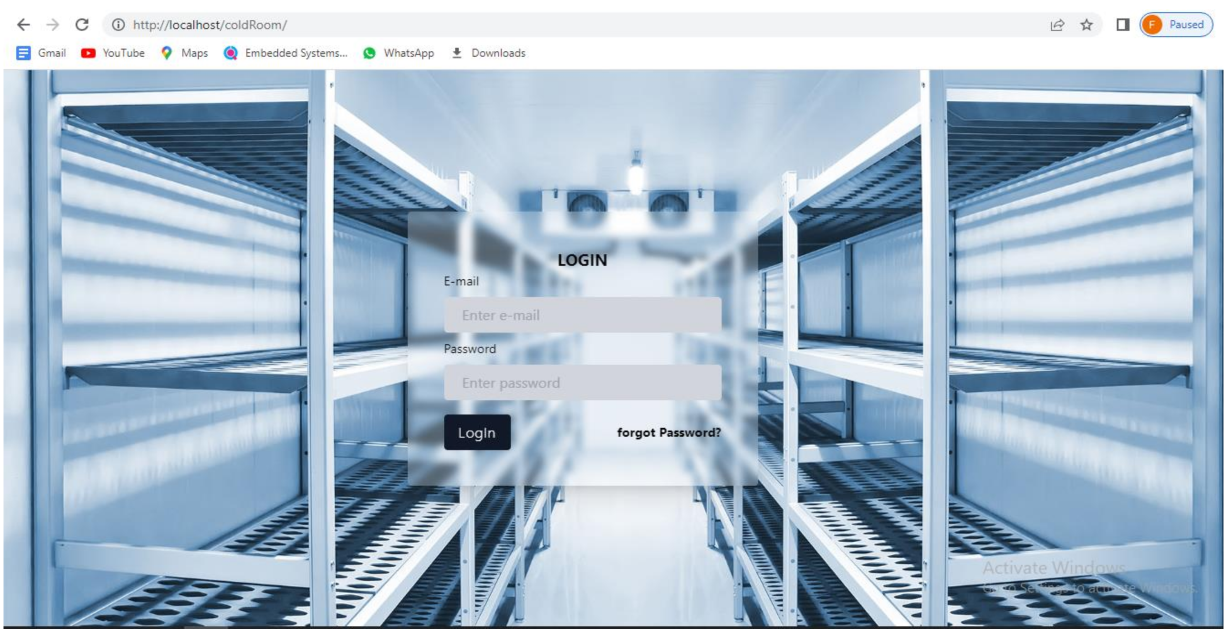

Figure 4.6 The user interface credential.

The system includes many distinct users, but each one of them is able to keep an eye on the all parameters of the cold room that are appearing on the dash board of the monitor. As I mentioned in my scope, I am now developing and installing two sensor nodes for storage for temperature and humidity and opening of the cold room as well.

4.2.2 Dashboard for The Designed System

The dashboard for the vaccine storage and its related sensor nodes is depicted in Figure 4.7. When the hardware is connected to the network, the system becomes operational, begins publishing data to an internet server, and begins displaying temperature and humidity graphs that show the temperature of refrigerators and whether the cold room is closed or open.

The user will no longer be able to access the sensor node's sensed parameters from the store as soon as it is not currently registered in the system. When the network is not in use, devices can be removed from it.

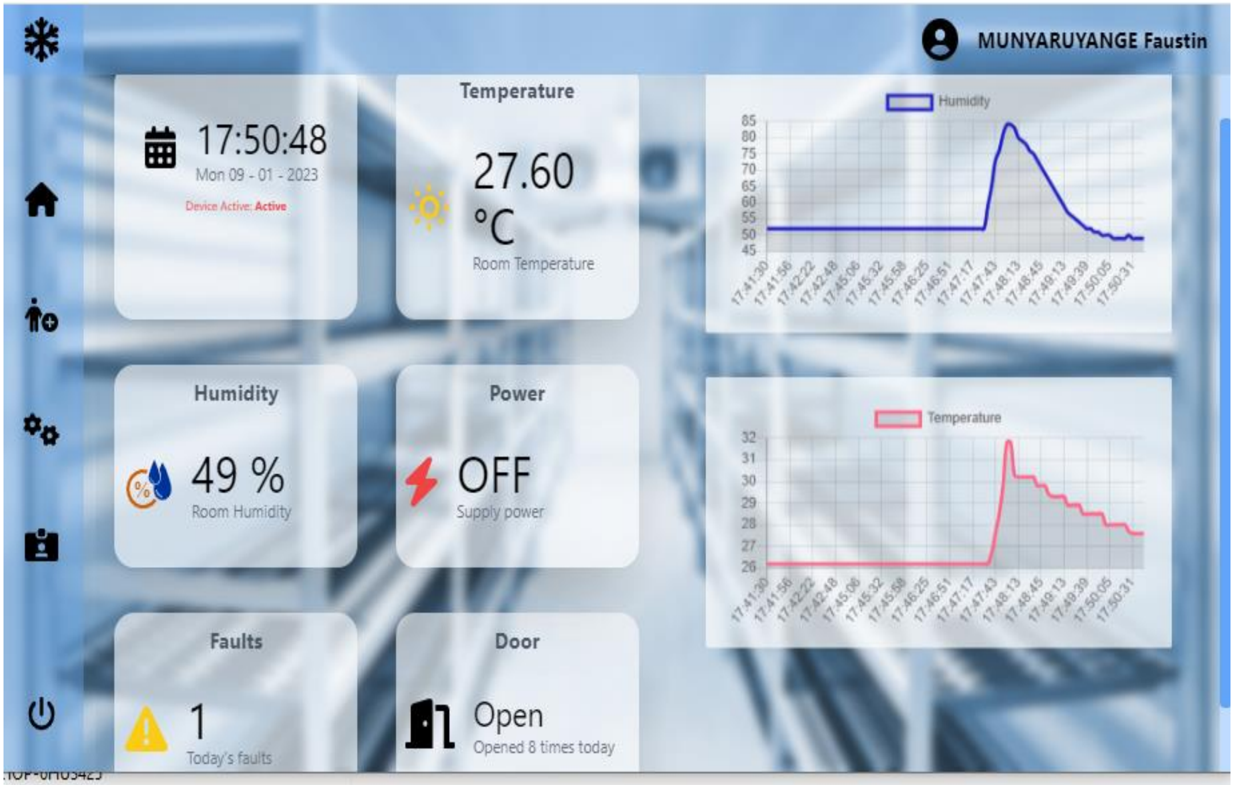

Figure 4.7 The dashboard information.

4.2.3 Humidity data loader in server

The figure 4.8 shows humidity graphical variation and a common time interval over which data are recorded in the database. The humidity is represented on y axis while the time is on x axis, the humidity is shown in percentage whereas the time is in hours and starts displaying from the real time the system is connected to the network and accessing the server.

Figure 4.8 The graphical variation of humidity and time interval on how data are loaded in database.

4.2.4 Temperature data loader in server

The figure 4.9 shows temperature graphical variation and a common time of interval over which data are recorded in the database. The temperature is represented on y axis while the time is on x axis, the temperature is shown in degree celcius whereas the time is in hours and starts displaying from the real time the system is connected to network and accessing the server.

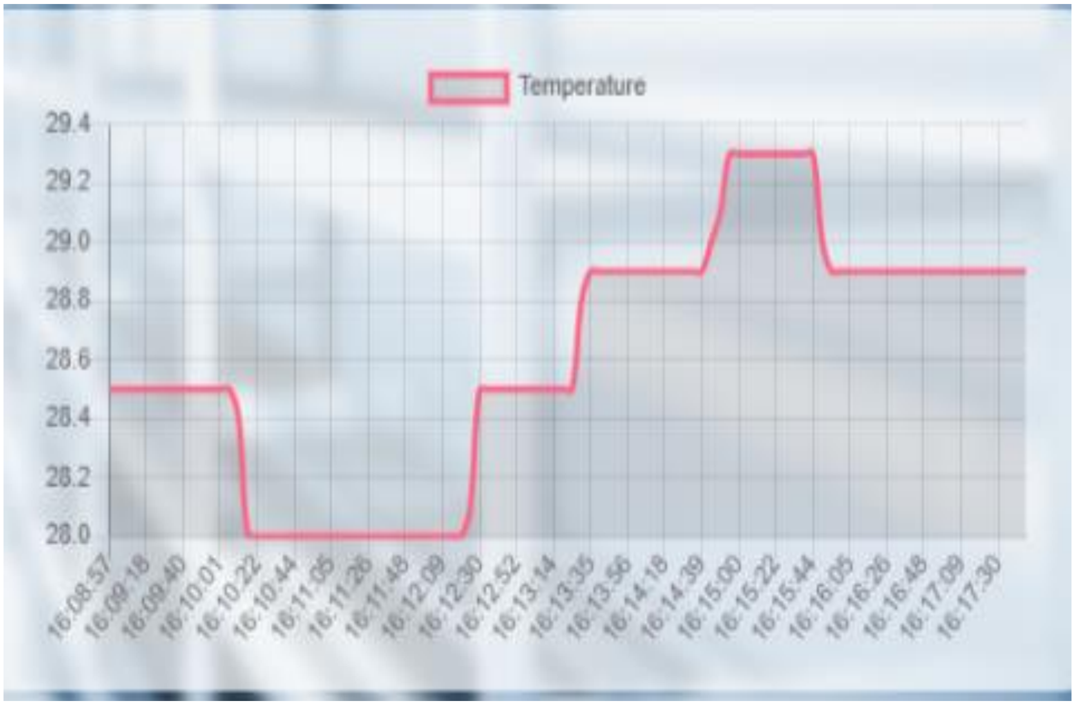

Figure 4.9 The temperature graphical variation and how data are recorded into the database at a common interval of time.

4.3 Vaccines storage Sensor node output

The microcontroller-connected DHT11 sensor and smart switch were used to monitor the temperature of the vaccine storage and storage closure or opening. The c^{++} programming language is used to program the microcontroller. The majority of vaccine retailers have internet access. This inspired me to employ the MCU8266 microcontroller node, which has the capacity to connect to the internet quickly via wired or wireless network infrastructures. Its quick processing time and seamless communication with the online application are other key features.

4.4 System Accuracy Analysis and Comparison.

Numerous experiments have been carried out to address the difficulties of vaccines cold room, as detailed in chapter two of this study. Although they can be used to monitor vaccine temperature, they lack a sensor to detect the closing and opening of the cold room for vaccines management.

The designed system has more advantages compared to the previous, since it allows for simple access to the data from anywhere and also facilitates the monitoring of closing and opening of the cold room for vaccines managements by using an online server to store the temperature data from the refrigerator. this work is more advantageous for local storage and provides real-time temperature monitoring of vaccinations. This has a dash board that indicates the overall number of faults on daily basis.

CHAPTER 5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion.

The results of this study showed that the current cold room monitoring strategy has a number of shortcomings. Manual vaccination temperature recording, sporadic power outages, opening of the storage and a lack of expertise in cold room monitoring techniques are a few of these. Because the system is able to gather vaccine temperatures, identify temperature changes, store opening and notify users anytime a temperature is discovered that is above or below the WHO recommended range, it is anticipated that it will assist prevent the waste of a significant number of vaccinations. Cold room technicians can see vaccination temperature data whenever and wherever they choose via a web application that has been developed. Additionally, it notifies cold room professionals through email in the event of any temperature or humidity excursions as well as the opening of a storage.

5.2 Recommendations

The research thesis urges the following actions:

- The hospital's vaccine technician should have local access to the currently in use vaccine monitoring system rather than reporting to the federal level.
- To enable cold chain technicians to use the new technology and ensure that cold rooms are properly monitored, there is a need to continuously expand their capacity through training.
- To prevent vaccine waste, the introduction of the monitoring system for vaccinations, which was already underway in hospital across the nation, should be accelerated.
- The RBC and MoH should make the system now in use for vaccine monitoring available to researchers so they can obtain the data they need to complete their reports on related fields.
- It is advised that future researchers develop a hybrid system that can send double notifications by email and SMS to increase the number of options for receiving information about the chilly room.
- The future researchers must focus on the way of improving the opening of cold room monitoring by using an advanced technology like finger print machine.
- Before acquiring foreign products, RBC and MOH should use locally created prototypes.

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APPENDICES

Appendix 1: Mode of Data Collection (Example the Questionnaire)

IMPROVED VACCINES MONITORING SYSTEM FOR RWANDA

This approach consists of a microcontroller as a core component where the collected data by sensors are loaded. The project aims is the ability to remotely monitor the temperature, humidity inside the cold room and ensure the safety and vaccination usage rate by sending an e-mail whenever the cold room is opened.

The following are questions used to gather information regarding the current cold room monitoring system and challenges faced by cold room technicians.

1. Do you use manual monitoring system for your cold room?

Mark only one oval.

- yes
- no

2. Can The monitoring system of cold room in place detect the cold room opening?

Mark only one oval.

- yes
- no *

3. Are you aware of WHO recommended temperature range for vaccines?

Mark only one oval.

- yes
- no

1/3

4. Does the system used for monitoring vaccines provide an email notification?

Mark only one oval.

- yes
- no

5. Can you know the power status of the cold room remotely?

Mark only one oval.

- Yes
- no

Appendix 2: The Utilized Codes

```
//DH11  Libraries
#include <Adafruit_Sensor.h>
#include <DHT.h>
#include <DHT_U.h>
// arduino json library
#include <ArduinoJson.h>

// wifi libraies
#include <ESP8266WiFi.h>
#include <ESP8266HTTPClient.h>
#include <WiFiClient.h>
// LCD libraris
#include <LCD_I2C.h>
//lcd globals
LCD_I2C lcd(0x27, 16, 2);
unsigned int lastLCD_update = 0;
#define displayInterval 2000
//esp8266 globals
const char* ssid = "Mara Z d";          // change this to your wireless network
const char* password = "Butunda!";  // change this to your password network
//Your Domain name with URL path or IP address with path
const char* serverName = "http://192.168.43.137/coldRoom/api/";

//DTH11 Globals
#define DHTPIN D5  // Digital pin connected to the DHT sensor
//the pins to connect the buzzer
#define buzzer D6

#define DHTTYPE DHT11  // DHT 11
DHT_Unified dht(DHTPIN, DHTTYPE);
uint32_t delayMS;
```

```
unsigned int lastDHT_Update = 0;
// send data to cloud glabals
unsigned int lastTime = 0;
#define SendDataInterval 2000
// the pin where the magnetic reed is connected
#define DoorSensor D0
// global data variables
float tempData = 0;
int humidityData = 0;
int voltageData = 0;
int doorData = 0;



void LCD_SetUp() {
  lcd.begin();
  lcd.backlight();
}



void DTH11_SetUp() {
  dht.begin();
  Serial.println(F("DHTxx Unified Sensor Example"));
  // Print temperature sensor details.
  sensor_t sensor;
  dht.temperature().getSensor(&sensor);
  // Print humidity sensor details.
  dht.humidity().getSensor(&sensor);
  delayMS = sensor.min_delay / 1000;
}

void WiFi_SetUp() {
```

```
  lcd.print("Connecting to ");  // You can make spaces using well... spaces
  lcd.setCursor(0, 1);          // Or setting the cursor in the desired position.
  lcd.print("Network .....");
  delay(2000);
  WiFi.begin(ssid, password);
  Serial.println("Connecting");
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("");
  Serial.print("Connected to WiFi network with IP Address: ");
  Serial.println(WiFi.localIP());

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("WiFi connected ");
  lcd.setCursor(0, 1);
  lcd.print("Successfuly  ");
}

void setup() {
  Serial.begin(9600);
  pinMode(DoorSensor, INPUT);  // define the rain sensor as an input
  pinMode(A0,INPUT);
  pinMode(buzzer,OUTPUT);

  LCD_SetUp();    // call of function to setup the lcd
  DTH11_SetUp();  // call to defiend function to setup the DTH11 sensor
  WiFi_SetUp();   // call of define function to set up the wifi of the esp8266

  delay(50);
}
```

```
void loop() {



  DTH11_SensorValues();  // get the temperature and humidity
  doorValues();
  lcdDisplay();
  currentSensor();
  sendData();  //send data to the cloud

  delay(10);
}
void lcdDisplay() {  // the function to display the data to the lcd
  if (millis() - lastLCD_update >= displayInterval) {
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("T: ");
    lcd.print(tempData);
    lcd.print("C  H:");
    lcd.print(humidityData);
    lcd.print("%");
    lcd.setCursor(0, 1);
    lcd.print("D: ");
    if (doorData == 1) {
      lcd.print("Open  P:");
      if(voltageData==1){
         lcd.print(" ON");
      }
      else{
         lcd.print("OFF");
      }
    } else {
      lcd.print("Closed  P:");
```

```
      if(voltageData==1){
        lcd.print(" ON");
      }
      else{
        lcd.print("OFF");
      }
    }

    lastLCD_update = millis();
  }
}
void doorValues() {
  if (digitalRead(DoorSensor) == HIGH) {
    Serial.println("door open");
    doorData = 0;
  } else {
    doorData = 1;
  }
}

void DTH11_SensorValues() {
  // Delay between measurements.
  delay(delayMS);
  if (millis() - lastDHT_Update >= delayMS) {
    // Get temperature event and print its value.
    sensors_event_t event;
    dht.temperature().getEvent(&event);
    if (isnan(event.temperature)) {
      Serial.println(F("Error reading temperature!"));
    } else {
      Serial.print(F("Temperature: "));
      tempData = event.temperature;
      Serial.print(event.temperature);
      Serial.println(F("°C"));
```

```
    }
    // Get humidity event and print its value.
    dht.humidity().getEvent(&event);
    if (isnan(event.relative_humidity)) {
      Serial.println(F("Error reading humidity!"));
    } else {
      Serial.print(F("Humidity: "));
      humidityData = event.relative_humidity;
      Serial.print(event.relative_humidity);
      Serial.println(F("%"));
    }
    lastDHT_Update = millis();
  }
}
void sendData() {
  //Send an HTTP POST request every define interval
  if ((millis() - lastTime) > SendDataInterval) {
    //Check WiFi connection status
    if (WiFi.status() == WL_CONNECTED) {
      WiFiClient client;
      HTTPClient http;
      // Your Domain name
      http.begin(client, serverName);
      //content-type header
      http.addHeader("Content-Type", "application/x-www-form-urlencoded");
      // Data to send with HTTP POST
      String httpRequestData = "tempData=" + String(tempData) + "&humidityData=" +
String(humidityData) + "&doorData=" + String(doorData) + "&voltageData=" +
String(voltageData);
      // Send HTTP POST request
      int httpResponseCode = http.POST(httpRequestData);
      Serial.print("HTTP Response code: ");
      Serial.println(httpResponseCode);
      String payload = http.getString();
```

```
Serial.println(payload);
if (httpResponseCode == 200) {
  // Stream& input;

  StaticJsonDocument<120> doc;

  DeserializationError error = deserializeJson(doc, payload);

  if (error) {
    Serial.print(F("deserializeJson() failed: "));
    Serial.println(error.f_str());
    return;
  }

  int overTemp = doc["overTemp"];          // 0
  int lessTemp = doc["lessTemp"];          // 0
  int overHimidity = doc["overHimidity"];  // 0
  int lessHumidity = doc["lessHumidity"];  // 0
  if (overTemp == 1 || lessTemp == 1 || overHimidity == 1 || lessHumidity == 1) {
    tone(buzzer, 450, 500);
    if (overTemp == 1){
      lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("Over");
      lcd.setCursor(0, 1);
      lcd.print("Temperature ");
      delay(1000);
    }
    if (overHimidity == 1) {
       tone(buzzer, 450, 500);
      lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("Over");
      lcd.setCursor(0, 1);
```

```
      lcd.print("Humidity ");
      delay(1000);
    }
    if (lessHumidity == 1) {
      digitalWrite(buzzer,HIGH);
      lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("Less");
      lcd.setCursor(0, 1);
      lcd.print("Humidity ");
      delay(1000);
      digitalWrite(buzzer,LOW);
    }
    if (lessTemp == 1) {
       tone(buzzer, 450, 500);
      lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("Less");
      lcd.setCursor(0, 1);
      lcd.print("Temperature ");
      delay(1000);
    }
  } else {
    tone(buzzer, 0, 0);
  }

} else {
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Lost Server....");
  delay(1000);
}
```

```
    http.end();
   } else {
    Serial.println("WiFi Disconnected");

    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("Wifi disconnected");
    delay(1000);
   }
   lastTime = millis();
  }
}
void currentSensor() {
  unsigned int x = 0;
  float AcsValue = 0.0, Samples = 0.0, AvgAcs = 0.0, AcsValueF = 0.0;
  for (int x = 0; x < 150; x++) {  //Get 150 samples
    AcsValue = analogRead(A0);     //Read current sensor values
    Samples = Samples + AcsValue;  //Add samples together
    delay(3);                      // let ADC settle before next sample 3ms
  }
  AvgAcs = Samples / 150.0;  //Taking Average of Samples

  //((AvgAcs * (5.0 / 1024.0)) is converitng the read voltage in 0-5 volts
  //2.5 is offset(I assumed that arduino is working on 5v so the viout at no current comes
  //out to be 2.5 which is out offset. If your arduino is working on different voltage than
  //you must change the offset according to the input voltage)
  //0.185v(185mV) is rise in output voltage when 1A current flows at input
  AcsValueF = (3.69 - (AvgAcs * (5.12 / 1024.0))) / 0.185;
  Serial.println(AcsValueF);  //Print the read current on Serial monitor
  delay(50);
  if(AcsValueF<=-7){
    voltageData=0;
  }
  else{
```

```
    voltageData=1;
  }
}
```