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DESIGNING A SMART REAL-TIME MONITORING DEVICE FOR PREGNANT WOMEN IN RURAL RWANDA

By:

DUSABE Diane
Reference Number: 221030759

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:

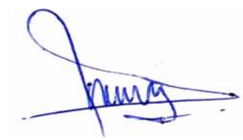
Dr. FREDERIC NZANYWAYINGOMA
And
Dr. NUHU ASSUMAN

DECLARATION

I, DUSABE Diane, declare that this dissertation entitled "Designing a Smart Real-time Monitoring Device for Pregnant Women in Rwanda" is my original work based on research and prototype and has not been submitted for any other degree or professional qualification.

Student Name: DUSABE Diane

Student Reference Number: 221030759

Student Signature: 

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CERTIFICATE

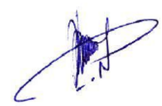
This is to certify that the project entitled “Designing a Smart Real-time Monitoring Device for Pregnant Women in Rwanda” is a record of original work done by DUSABE Diane 221030759 MSc. Degree student in Biomedical Engineering.

This work has been submitted under the guidance of Dr. Frederic NZANYWAYINGOMA and Dr. NUHU ASSUMAN

Main Supervisor:

Dr. of Dr. Frederic NZANYWAYINGOMA

Co-Supervisor:



Dr. NUHU ASSUMAN

Biomedical Engineering Master’s Program Coordinator

Dr. Gerard Rushingabigwi

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Abstract

This study investigates the challenges and potential solutions for enhancing maternal healthcare in rural Rwanda by using a smart real-time monitoring device. Data collection involved interviews with pregnant women in rural communities to understand their difficulties in accessing early pregnancy check-ups. A proposed system diagram illustrates the integration of vital parameters monitoring, including temperature, heart rate, and SPO2, through sensors like the MAX30102 and LM35 connected to an Arduino Nano. The system's hardware components, such as the GSM module, facilitate real-time data transmission to pregnant women's phones. Simulation results demonstrate the system's effectiveness in monitoring vital signs and providing timely alerts for abnormal readings. Compared to existing systems, the proposed device offers remote monitoring and communication capabilities, overcoming limitations posed by distance and time constraints associated with traditional healthcare models. Overall, this study underscores the potential of technology-driven solutions in improving maternal healthcare outcomes in rural areas, with implications for scalability and future development opportunities.

Keywords: Arduino Nano; temperature sensor; heartbeat rate sensor; and SPO2 sensor.

List of Acronyms

GSM: Global System for Mobile Communications.

SPO2: Saturation of Peripheral Oxygen

LM35: Linear Monolithic 35

SDGs: Sustainable Development Goals.

MMR: Maternal Mortality Ratio

CHWs: Community Health Workers

LCD: Liquid-Crystal Display

WHO: World Health Organization

UNICEF: United Nations Children's Fund

UNFPA: United Nations Population Fund

ITU: International Telecommunication Union

ANC: Absolute Neutrophil Count

ADC: Analog-to-Digital Converter

SMS: Short Message Service

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CHAPTER 1. GENERAL INTRODUCTION

1.1. Introduction

Maternal mortality remains a pressing global issue, with progress towards achieving the Sustainable Development Goals (SDGs) by 2030 falling short. The majority of maternal deaths, over 99% in 2020, occur in low- and middle-income countries, particularly in Sub-Saharan Africa and South Asia[1]. These deaths disproportionately affect the poorest countries, including those affected by fragility and conflict. Lack of access to quality healthcare and high fertility rates contribute to these preventable deaths[2].

In Rwanda, 93% of births are delivered in a health facility, most (91%) in a public sector facility, and only 5% of births are delivered at home[3]. Maternal mortality includes deaths of women during pregnancy, delivery, and within 42 days of delivery excluding deaths that were due to accidents or violence. With a population density of 525 per Km^2, the maternal mortality ratio (MMR) stands at 203 maternal deaths per 100,000 live births [4].

Pregnancy is an important phase for the health of the woman health as well as her child. All the precautions and steps taken to ensure better health and seamless baby delivery after 9 months are crucial [5]. During this period, there is a possibility of various complications due to maternal infection, bleeding, and variation in blood pressure, which may result in gestational diabetes and weight gain during pregnancy. During pregnancy, some women may face the problems of high blood pressure which is called gestational hypertension which can impact the kidneys of the mother as well as other organs [6]. It is recommended that a pregnant woman carry out routine check-ups during which various parameters, for example, body weight, temperature, blood pressure, heart rate, and fatal movements are recorded and analyzed to determine the health of both the mother and neonatal. This reduces the chances of pregnancy-related complications that could endanger the lives of the mother and child

Most deaths of mothers and neonatal babies occur around childbirth from preventable causes. A doctor or nurse cannot be with each patient all the time. Presently, patients cannot be watched continuously without human help. These complications lead to risks such as preeclampsia disease and other cardiovascular diseases that can occur without any warning at any time during pregnancy[7].

The proposed research will focus on designing a smart real-time device for monitoring women's pregnant detection. The device will be designed to be used in rural areas, and they have the potential to revolutionize healthcare in Rwanda by reducing maternal mortality rates, limiting unnecessary hospital visits, and decreasing transportation fees.

This study reviews the existing system operating by utilizing sensors such as the heart rate sensor, temperature sensor, blood pressure, and SPO2 sensor in Rwanda (Reference) but This research focused on the heart rate sensor, temperature sensor, and SPO2 sensor sensors to collect data from pregnant women, which is transmitted to their phones using the GSM module connected to a microcontroller called ARDUINO. The results are displayed on an LCD screen and sent via text message to the woman's phone, providing timely updates on her health parameters. The data is then processed, analyzed by Community Health Workers (CHWs), and sent in real-time.

This technology aims to assist individuals who lack timely access to medical assistance or live far from hospitals by providing daily updates on their health status. Through this research, healthcare providers will enhance their knowledge and capacity to support pregnant women. With four doctor visits and four evaluations by Community Health Workers out of the scheduled eight appointments, pregnant women receive comprehensive monitoring, a smart real-time monitoring device can have a positive impact on the lives of many people in Rwanda.

1.2. Problem Statement

Pregnancy-related issues are still a major source of worry and are especially prevalent in low- and middle-income countries like Rwanda. According to the trends of maternal mortality from 2000 to 2020 estimated by WHO, UNICEF, UNFPA, World Bank Group, and UNDESA in 2023, around 800 women died each day in 2020 from preventable causes connected to pregnancy and childbirth, which is equivalent to around one death every two minutes[1]. Reducing maternal mortality to less than 70 maternal deaths per 100,000 live births by 2030 is the target of the Sustainable Development Goal (SDG). Recent data from the Rwanda demographic and health study revealed that for the five years before the study, the infant mortality rate in Rwanda was 33 deaths per 1,000 live births while 19 infant deaths per 1,000 live births was the neonatal mortality rate. The mortality rate for children under five was 45 per every 1,000 live births[4]. This indicates that approximately 1 in every 22 children dies before age five. Some maternal and infant deaths occur around the delivery time due to preventable causes neither a doctor nor a nurse their physically present with every patient at once [3].

Smart real-time monitoring devices have the potential to revolutionize healthcare in Rwanda by reducing maternal mortality rates, limiting hospital visits, and decreasing transportation fees.

However, more research is needed to address the implementation challenges of this new technology, such as privacy, user education, security, and accessibility.

1.3. Research Questions

The following questions are the baselines that guided this study:

1. What monitoring system is employed by community healthcare workers during your pregnancy period?
2. How often should you meet with a community healthcare worker before delivery?
3. Is this the first time to hear about the design of a smart real-time device for pregnant women?
4. How would you welcome or appreciate the introduction of a smart real-time device for pregnancy in your village?

1.4. Hypotheses

The implementation of a smart, real-time monitoring device for pregnant women in rural Rwanda will lead to an increase in the number of antenatal care visits, as the device provides continuous health monitoring and prompts timely medical interventions, ultimately improving maternal and neonatal health outcomes.

1.5. Objectives

1.5.1. General Objective

This research aims to design a smart real-time monitoring device for pregnant women in Rwanda.

1.5.2. Specific Objectives

- To investigate current pregnancy monitoring systems utilized by women in a rural setting in Rwanda.
- To provide technical support with existing pregnancy monitoring systems.
- To design and prototype a real-time pregnancy monitoring system for women in a rural setting in Rwanda.
- To evaluate the functionality of the designed device.

1.6. Study Scope and Area

This study, conducted in rural areas in Rwanda, focuses on understanding the challenges pregnant women face in accessing early pregnancy check-ups, aiming to reduce risks for both mothers and neonates. Interviews were used to collect data in RWIMIYAGA, GAKOMA, and BWEYEYE, distributed in each sector. This approach emphasizes the importance of early check-ups and regular monitoring, potentially reducing maternal and neonatal mortality rates in rural Rwanda.

1.7. Significance of the Study

This system has the potential to contribute to the reduction of maternal and newborn mortality rates. This will greatly reduce the need for unnecessary hospital visits and transportation, saving both time and money. Additionally, the system should be designed with user-friendliness in mind, considering the technical knowledge and capabilities of pregnant women. Proper training and support for healthcare professionals in utilizing and interpreting the system's data are also crucial for its successful implementation.

1.8. Organization

Chapter One introduces the topic, its importance, and the research objectives. Chapter Two looks at what other people have already found out about pregnant women monitoring. Chapter Three outlines the methodology, detailing the research design, participants, and data collection methods. Chapter Four will focus on presenting the data findings and analysis, while the system design will be presented in Chapter Five. Chapter Six focuses on recommendations and conclusions. Recommendations suggest practical steps based on the findings, while the conclusion summarizes the key points of the study and its implications.

1.9. Summary

This chapter introduces the problem of high maternal mortality rates in Rwanda, particularly in rural areas, where access to timely healthcare is limited. It highlights the potential of a smart real-time monitoring device to address this issue by providing pregnant women with continuous updates on their health status and reducing unnecessary hospital visits. This study presents the specific research questions and objectives, focusing on understanding the current monitoring systems used by rural women, designing and testing a prototype of the smart device, and evaluating its impact on reducing maternal and unborn mortality rates.

CHAPTER 2. LITERATURE REVIEW

The literature review will focus on maternal and child mortality in rural areas, exploring the role of technology, particularly cell phones, in Healthcare. It will also examine the design and effectiveness of smart monitoring devices for pregnant women, aiming to provide a comprehensive understanding of how technology can improve maternal healthcare in rural communities.

2.1. Maternal and child mortality in rural areas

According to World Health Organization (WHO), approximately 830 women die, every day, from preventable causes related to pregnancy and childbirth [8]. The ratio of maternal mortality is high in poor and rural areas, and almost 99% of maternal deaths take place in developing countries. Rwanda is the most densely populated country in Africa with 415 inhabitants per square kilometer. The newly released Rwanda Demographic Health Survey (DHS) estimates Maternal Mortality Ratio (MMR) at 476 per 100,000 live births [9], down from 750 per 100,000 estimated in 2005 [10]. Nevertheless, Rwanda is among the sub-Saharan African countries where the largest total percentage decline of MMR (51% reduction) was registered between 1990-2008 [8]. Despite the above-stated progress, the country has yet to meet the MDG 5, corresponding to 325 per 100,000 live births.

During pregnancy, childbirth, and weeks after childbirth, all women need support and timely access to skilled nursing care. However, factors that prevent women from receiving care during pregnancy and childbirth are poverty, delays, lack of information and awareness, lack of adequate healthcare services and skilled health professionals, home deliveries, and cultural practices [8]. There were 1,160 maternal deaths reported from 2009–2014. Obstetric hemorrhage was the most frequent cause of death (39%), followed by non-obstetric complications (19.3%), pregnancy-related infection (11.3%), and hypertensive disorders (10.2%)[11]. Most maternal deaths can be avoided since the healthcare solutions to prevent and manage complications of pregnancy are widely known [8],[10].

2.2. The use of technology in healthcare

New technology influences many areas of our life. Both Health Care (HC) professionals and patients meet new technologies in their activities. Examples are the electronic storage of health data, using mobile apps supporting diverse activities, telemedicine, or robotic surgery. Technology, in general, become an indispensable component of current HC welfare.

But, “technology alone is not enough it needs to be combined with innovations in processes to have the greatest effect, to fit into the context and to deliver qualitative professional care[12].

The use of technology in health has gained much attention in recent times[12]. With the rapid growth in information, communication, and technologies (ICT), the field of eHealth has now emerged in many forms, and its potential has been experimented on and discussed globally. eHealth is frequently becoming an essential part of people’s everyday lives and can improve the delivery and cost of healthcare and the quality of the patient experience[13].

In addition, it also offers significant opportunities for improving data analysis and replacing the traditional paper-based healthcare system where developing a national or regional overview of patient statistics is extremely difficult.

This study highlights the system's user-friendly approach, allowing real-time accessibility of health data for healthcare professionals and supporting multiple users in a single account, enabling collaborative monitoring by remote specialists and caregivers[14].

Various mHealth initiatives have been piloted in sub-Saharan Africa including Uganda’s RapidSMS system to support the management of the rollout of malaria’s rapid diagnostic test by the country’s National Malaria Control Program[9]. Zambia’s SMS system to reduce delays in sending infant HIV testing results from centralized laboratories to remote rural health facilities[15], and Malawi’s SMS system to improve communication among health workers for family planning and reproductive health in rural areas[16].

In Nigeria, while the use of electronic communication for the registration of birth has been reported[17], there has been no evaluation of the use of mobile technology devices to improve maternal health services. Nigeria has a wide mobile phone usage with 89.1% of the population using mobile technology devices[17]. The wide coverage and use of mobile phones in Nigeria should provide an effective medium for increasing women’s access to skilled maternal care.

Rwanda has recently developed a comprehensive Information Technology strategy plan that includes eHealth (the combined use of electronic communication and information technology in the health sector). RapidSMS Rwanda: an initiative originating from Rwanda aimed at saving the lives of expectant mothers, and children below two years through improved access to antenatal, and postnatal care and a real-time emergency response system. Information is shared via SMS[18]. Community workers are equipped with mobile devices which they use to collect data and use it in real time on maternal and neonatal indicators.

The indicators are recorded and reminders are generated which are sent to the expectant mothers via SMS[18]. The emergency system called RED Alerts is also used[19]. Improvement in data speeds, miniaturization of computers and smart devices with higher levels of reliability and security, decreasing costs, and increasingly user-friendly features are becoming the main reasons for adopting eHealth solutions in our daily lives[20]. Technologies including computers, smartphones, communication systems, and eHealth applications can play an important role in minimizing these factors and can contribute to a significant reduction in maternal mortality around the world[21].

In the healthcare system, face-to-face meetings are always the most useful and important contact. However, a professional network of patients and health professionals can be vital to both sides. Smartphone-based devices in combination with internet connectivity have the potential to create a network of healthcare providers and patients to reduce their communication gap. Such a network can create remarkable and unprecedented opportunities for improving maternal and child health outcomes by facilitating interactions and information sharing between health professionals and patients[22].

2.3. Cell phone in Healthcare

Maternal and child health initiatives across sub-Saharan Africa are embracing the use of electronic or mobile technology to improve access to and use of skilled obstetric care, particularly in marginalized and vulnerable populations. These initiatives have proven to be effective in improving women's use of health facilities, enhancing two-way communication between healthcare workers and pregnant women, and increasing pregnant women's self-efficacy through the provision of relevant health information[23].

The International Telecommunication Union (ITU) estimated 5.9 billion the number of mobile subscribers in 2011, with global penetration estimated at 87% of which 79% in the developing world[21]. The number of mobile phones in the world was 97 per 100 people at the end of 2014[9]. Mobile phones are increasingly used by more women, and some of them are from the poorest and most remote areas of the world [9]. Mobile and wireless technologies can provide exciting low-cost highly-reachable healthcare services such as managing chronic diseases, empowering elders and pregnant women, reminding people to take medicines at the proper time, facilitating health services to remote areas, generating customized health information and improving the outcomes of health and medical systems[10].

Gifted Mom is a mobile app in Cameroon that helps expectant mothers monitor their health through text messages. It reminds mothers to attend antenatal care, stressing its importance in reducing maternity mortality[24].

Similarly, a cluster-randomized, controlled trial[25] evaluated the effect of a mobile phone intervention on perinatal mortality in a low-resource setting in Zanzibar

For instance, a mobile phone-based system[26] was implemented in Rwanda to monitor the information on pregnancy and newborns. An SMS-based project was developed to trace the number of pregnancies and their related complications in the community through instant messaging. The use of mobile to support medical and public health practice and research (mHealth) is gaining increased attention as it provides opportunities to connect people rapidly, reducing, therefore, delays across the chain of health decisions, and positively affecting the lives of millions of underserved populations [26].

2.4. Smart monitoring devices for pregnant women

A study aimed to monitor the high risks of pregnant women to premature births utilized body sensors to track uterine contractions[27]. When the contractions reached a certain threshold, patients were alerted through mobile applications. This approach seeked to reduce premature births by providing timely interventions to at-risk pregnant women[27].

In 2012, a study was done in the MUSANZE District. Messages were sent to the hospital to alert the need for emergency services to support pregnant women with problems. This helped pregnant women to get quick treatment when needed through connection of different actors of the healthcare system [26] Another study conducted in a developing country, including Rwanda, focuses on monitoring pregnant women in rural areas.

This system targets specific pregnancy health conditions using pulse and temperature sensors connected to an Arduino microcontroller. It collected and analyzed data, then sent SMS to healthcare workers for timely intervention and care. This study only looked at a few health measures like pulse and temperature, ignoring other important ones for monitoring pregnant women's health. To achieve better maternal health, it is vital to consider many health factors, not just a few[26].

2.5. Summary

The literature on maternal and child mortality in rural areas underscores the significant challenges faced by these communities, including limited access to healthcare facilities and skilled birth attendants. Factors such as socioeconomic disparities, inadequate infrastructure, and cultural beliefs contribute to higher mortality rates in these areas. Interventions such as improved prenatal care, skilled birth attendance, and community health education programs are crucial for reducing mortality rates.

In the realm of healthcare technology, cell phones have emerged as powerful tools for improving healthcare access and delivery in rural areas. Mobile health initiatives leverage cell phones for teleconsultations, health education, and data collection, enhancing communication between patients and providers and facilitating timely information dissemination.

Smart monitoring devices for pregnant women offer a promising solution for improving maternal and neonatal health outcomes. These devices enable continuous monitoring of vital signs and pregnancy-related metrics, allowing for early detection of complications and timely interventions. By facilitating remote monitoring and personalized care, smart monitoring devices have the potential to significantly impact maternal and child health in rural areas.

CHAPTER 3. RESEARCH METHODOLOGY

3.1. Methodology

3.1.1. Population and sample

This study was conducted with a focus on rural communities in Rwanda. The system aimed to understand pregnant women's difficulties in getting early pregnancy check-ups, to lower risks for mothers and newborns. The women in Rwanda treated during pregnancy are monitored by a community health worker in the village using easy technology**.** They should go to the health center at least four times in all trimesters and be followed by community healthcare workers[28].

3.1.2. Data Collection and Procedure

Interviews were used as the main way to collect data in selected rural areas, providing a broad view of maternal healthcare. Data were collected in the three different sectors by using a questionnaire (Appendix 1), with 20 questionnaires distributed in each sector namely RWIMIYAGA, GAKOMA, and BWEYEYE. These sectors were chosen due to their representation of rural areas in Rwanda, ensuring that the findings and device design apply to similar regions.

3.2. Proposed System Diagram

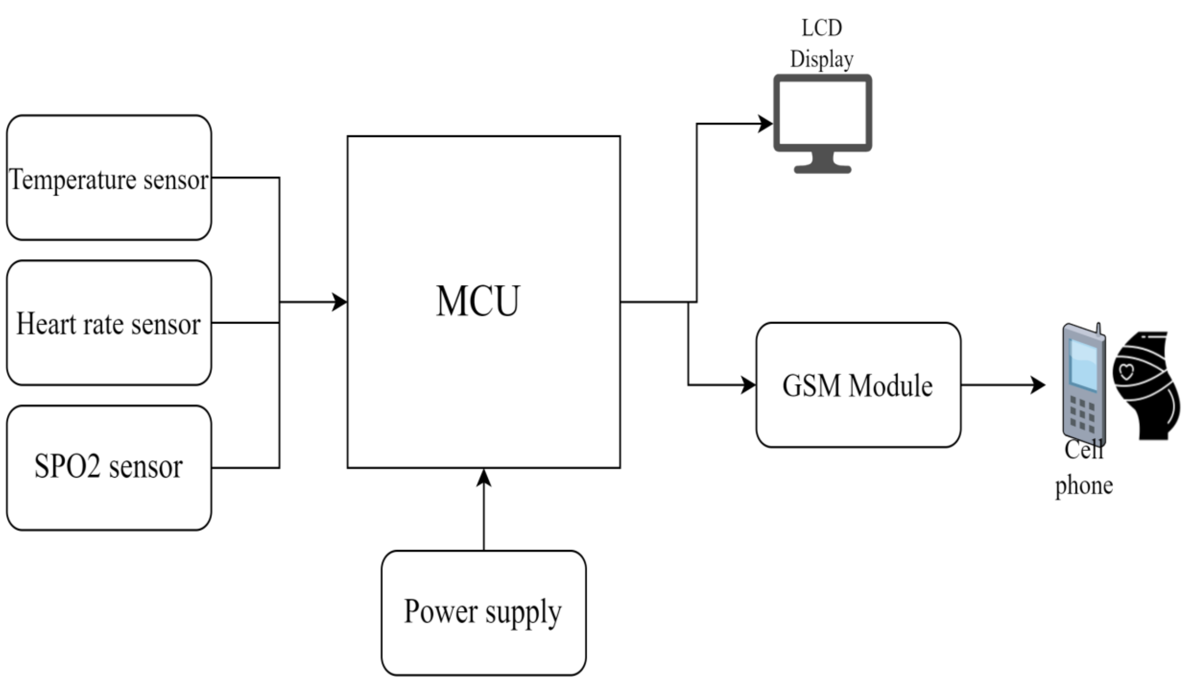


Figure 3. 1: The System Block Diagram

In the proposed system, some vital parameters of pregnant women like temperature, heart rate, and SPO2 are measured to achieve real-time health monitoring of pregnant women. This architecture of the proposed system is shown in Figure 3.4. Block consists of various sensor units like heart rate detector, temperature sensor, oximeter, and blood pressure. The MAX30100 sensor is used to measure the heartbeat and SPO2 of the patient. It is usually clipped onto a fingertip to get a count of heartbeat. It gives the approximate amount of blood oxygen. Pulse oximetry works on the absorption characteristics of red and infrared (IR) light of oxygenated and deoxygenated hemoglobin. Blood oxygen concentration can be calculated from the ratio between the absorption of red light and IR light by the hemoglobin. The change in blood volume is used to detect the heart rate by the amount of light that passes through the finger. The sensor LM35 is used to measure human body temperature. It converts temperature measurements to digital form using an analog-to-digital converter (ADC). All these data parameters are collected on the Arduino and then sent to the LCD and the GSM module. It helps to send the final results to the women's phone through a message, which is the normal or abnormal rate.

3.3. Hardware and Software Used in this Project

3.3.1. Hardware Components

3.3.1.1. Arduino NANO

In this proposed system, the Arduino Uno is used as the microcontroller to process data from sensors related to monitoring pregnant women in real-time. Arduino Nano is a smart board used to create prototypes quickly. It is part of the Nano family and is great for projects that need to fit on a breadboard. The Nano has an ATmega328 microcontroller running at 16 MHz, similar to the Arduino Duemilanove. It has 20 digital input/ output pins, 6 of which can be used for PWM, 8 analog pins, and a mini-USB port[29].

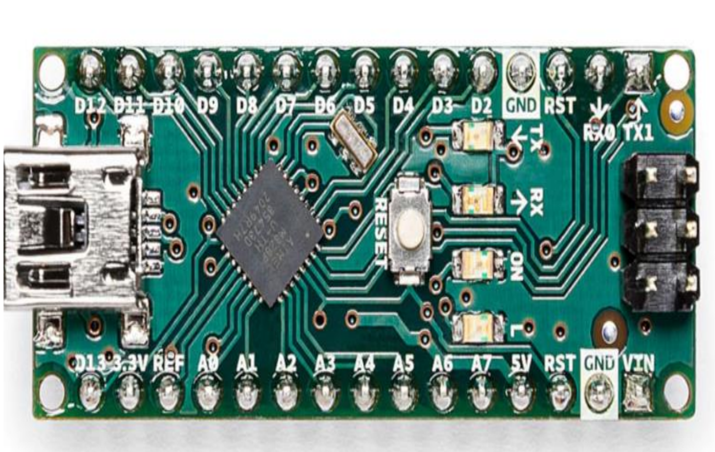


Figure 3. 2: Arduino Nano is used in circuit

3.4.1.2. Global System for Mobile Communications

Global System for Mobile Communications (GSM) standards define how second-generation (2G) cellular networks operate, allowing mobile phones and tablets to communicate and access basic services like voice calls, SMS texting, and slow data[30]. It utilizes a cellular network structure with base stations serving divided zones and employs time-division multiple access (TDMA) for multiple phones to share frequencies. Subscriber information is stored and authenticated on SIM cards. While largely superseded by faster 3G and 4G technologies in many areas, GSM remains operational in some parts of the world and serves as the foundation for later mobile network generations. For this project, GSM works in the device to provide pregnant women with information about their final results through messages[31].

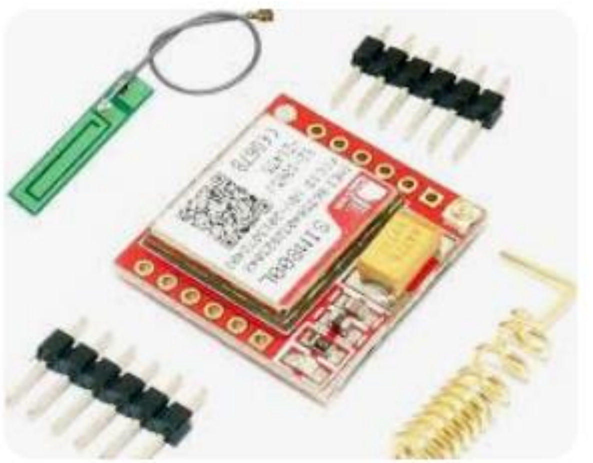


Figure 3. 3: The Global System for Mobile Communications used in the circuit

3.4.1.3. Temperature sensor

During pregnancy, the body of a woman undergoes many changes. One of these changes is an increase in body temperature, along with other symptoms like a growing belly, changes in the skin, and morning sickness [32]. This temperature rise can be uncomfortable, especially when combined with the discomfort of weight gain. It is normal for body temperature to increase slightly during pregnancy, but it is important to avoid overheating, as this can be dangerous [32]. Keeping the core body temperature below 39 degrees Celsius is essential for the health of both the mother and the baby[33]. Some women experience a "pregnancy glow," which is a combination of joy and a flush of heat. This is caused by the rising of the body temperature at each stage of pregnancy. Pregnant women may also notice an increase in body temperature and perspiration, even during sleep. Hormonal changes during pregnancy can also contribute to a slight rise in body temperature [34]. As the body prepares for the arrival of the baby, it increases blood volume to transport oxygen and nutrients to the baby[33]. This increase in blood volume causes the heart to work harder, which can lead to a rise in body temperature. Pregnant women need to avoid excessive heat exposure, as it can have negative effects on both the mother and the unborn child. Therefore, it is very important to monitor the temperature of pregnant women regularly to prevent any problems. The LM35 is a temperature sensor known for its accuracy, as its output voltage changes with temperature. Temperature ranges from -55°C to 150°C can be measured using this cost-effective IC. An ADC-capable microcontroller like Arduino can easily be attached to it[35].

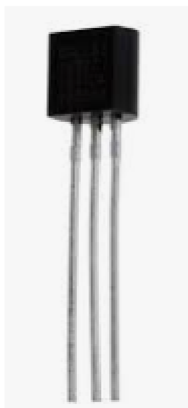


Figure 3. 4:LM35 Temperature Sensor

3.4.1.4. MAX30102 sensor

MAX30102 sensor is a device that is used to monitor the heart rate and it is also used as a pulse oximeter. The sensor comprises two light-emitting diodes, a photodetector, and a series of low-noise signal processing devices to detect heart rate and perform pulse oximetry[36]. The MAX30102 Heart Rate Oxygen pulse sensor offers several key features and specifications. It operates within a voltage range of 1.8V to 3.3V, making it compatible with a variety of devices. With an input current of 20mA, it maintains efficiency while in operation. The sensor also boasts high sample rate capability, allowing it to capture data at a high speed, and fast data output capability, ensuring that results are quickly available for analysis[37]. These features make the MAX30102 sensor a flexible and dependable choice for monitoring heart rate and oxygen levels.

Figure 3. 5:MAX30102 Heart Rate Oxygen Pulse Sensor

3.4.1.5. Lithium battery

A lithium-ion battery is a type of rechargeable battery in which lithium ions move from the negative electrode (anode) to the positive electrode (cathode) during discharge and back when charging. This movement of ions creates the flow of electric current in the battery, allowing it to store and release energy[38]. The energy density of lithium-ion batteries with a high discharge voltage of 3.6V is almost double that of nickel-cadmium batteries. Additionally, these batteries have shown excellent cycle life and a higher level of inherent safety[39]. Lithium-ion batteries are commonly used in portable devices, electric vehicles, and other applications requiring high-energy density and rechargeable capability.

Figure 3. 6: Lithium battery used in circuit

3.4.1.6. Charging module

A charger module is a device used to charge rechargeable batteries. It consists of circuitry that regulates the charging current and voltage to ensure safe and efficient charging of the battery. Charger modules are commonly used in various electronic devices, such as smartphones, laptops, and power banks, to recharge their internal batteries. This adaptable charger module utilizes the TP4056 IC, which is a linear charger chip designed for single-cell lithium-ion batteries. It can be powered by either a USB connection or a wall adapter. The module includes features such as current monitoring, under-voltage lockout, automatic recharging, and two status LEDs that indicate when the charging is complete and when an input voltage is present[40].

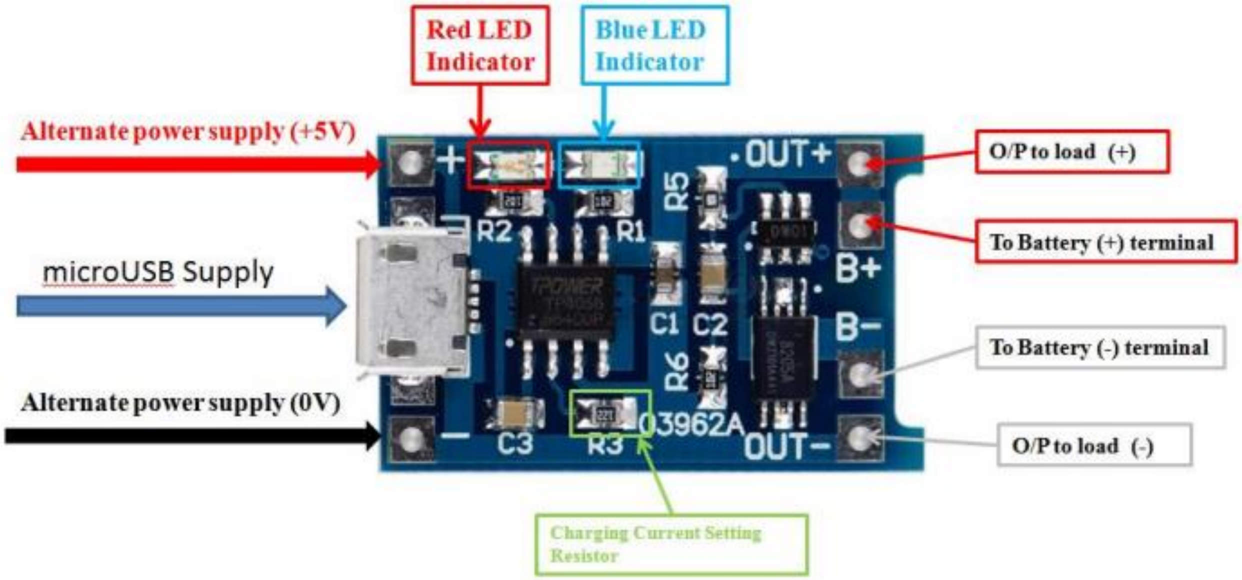


Figure 3. 7: Charge module used in the circuit

3.4.2. Software Used

3.4.2.1. Arduino Software (IDE)

The Arduino software, also known as the Arduino IDE, is open source. Writing code in the Arduino IDE is simple, and you can easily upload it to the board. It's user-friendly for beginners but also offers enough flexibility for advanced users. You can use it on Windows, Mac OS X, and Linux. Experienced programmers can extend its capabilities since it is open source. The Arduino IDE supports the languages C and C++, following special rules for code structure. It also comes with a software library from the Wiring project, which offers many standard input and output procedures[41].

3.5. System functionality

This section describes how the system works and the steps it follows. It uses diagrams that illustrate the sequence of actions and different situations the system manages.

3.5.1. System flowchart

3.5.1.1. Flowchart of sensor data monitoring

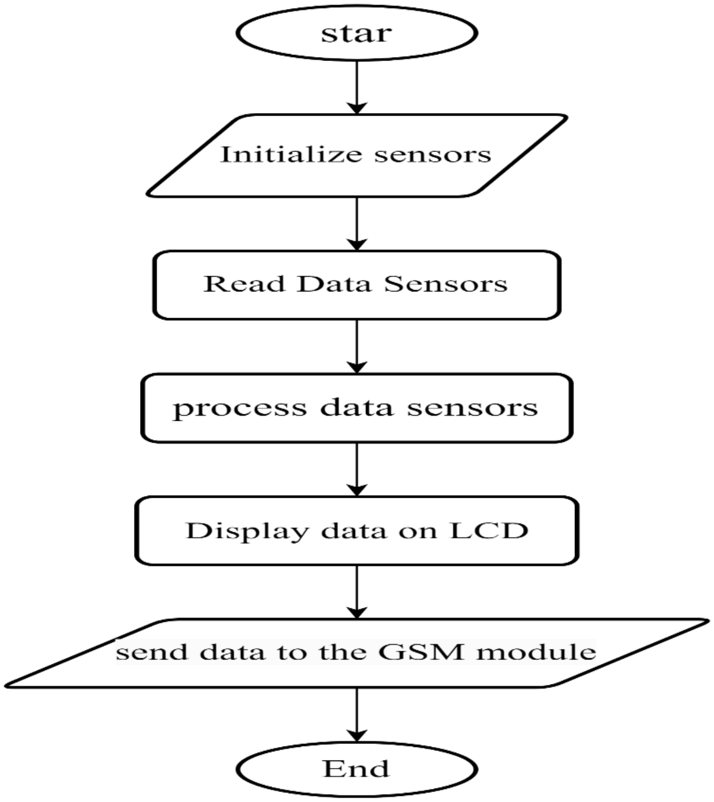


Figure 3. 8: flowchart of sensor data monitoring

The flowchart measures heart rate, temperature, and oxygen saturation (SpO2) using sensors, processes the data, displays it on an LCD, and then sends it via a GSM module. It's a basic vital signs monitoring system

3.5.2. The flowchart monitors vital signs

The flowchart monitors vital signs like heart rate, temperature, and oxygen and sends a message to the woman's phone based on the reading. If all readings are within normal ranges, it sends a normal data message. If any reading is abnormal, it sends an alert message.

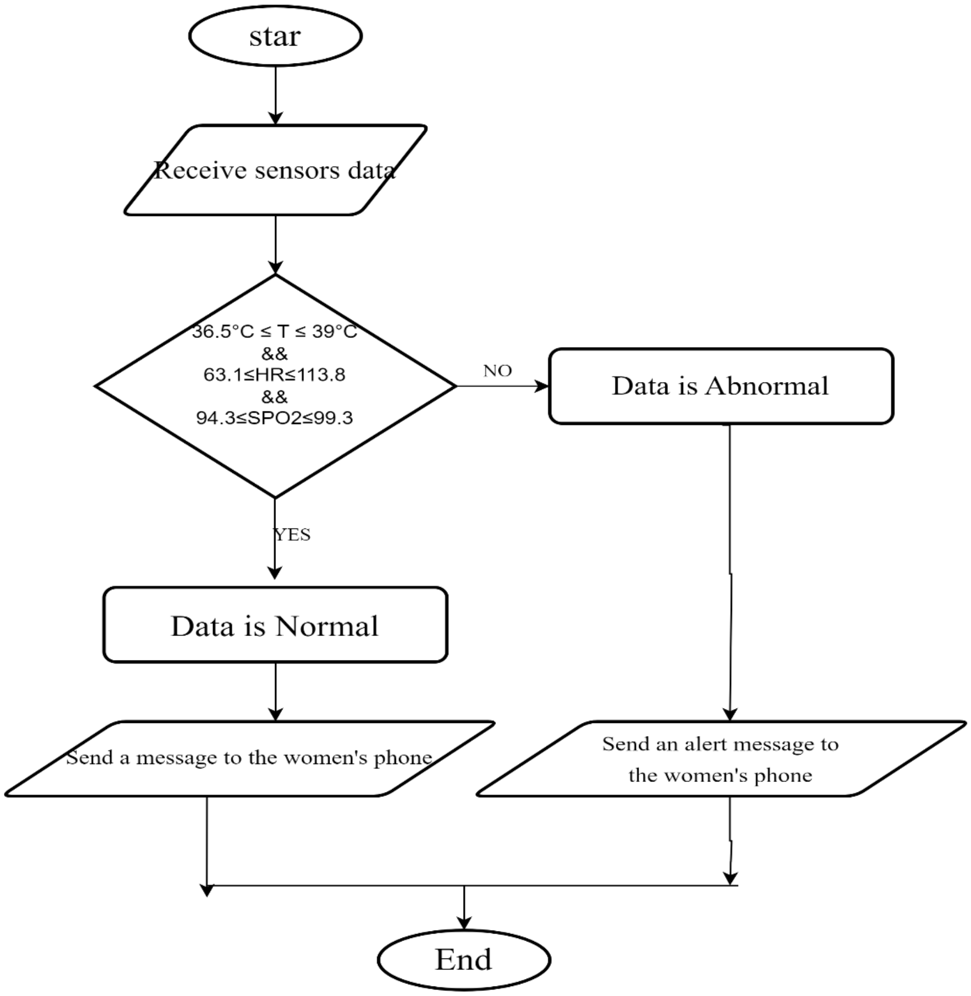


Figure 3. 9: The flowchart monitors vital signs

3.5.3. The System Use Case Diagram

In a Use Case Diagram for designing a smart real-time monitoring device for pregnant women, you would typically have three actors: the pregnant women, the community health worker, and the embedded system. Here's a basic outline of how these actors might interact with the system:

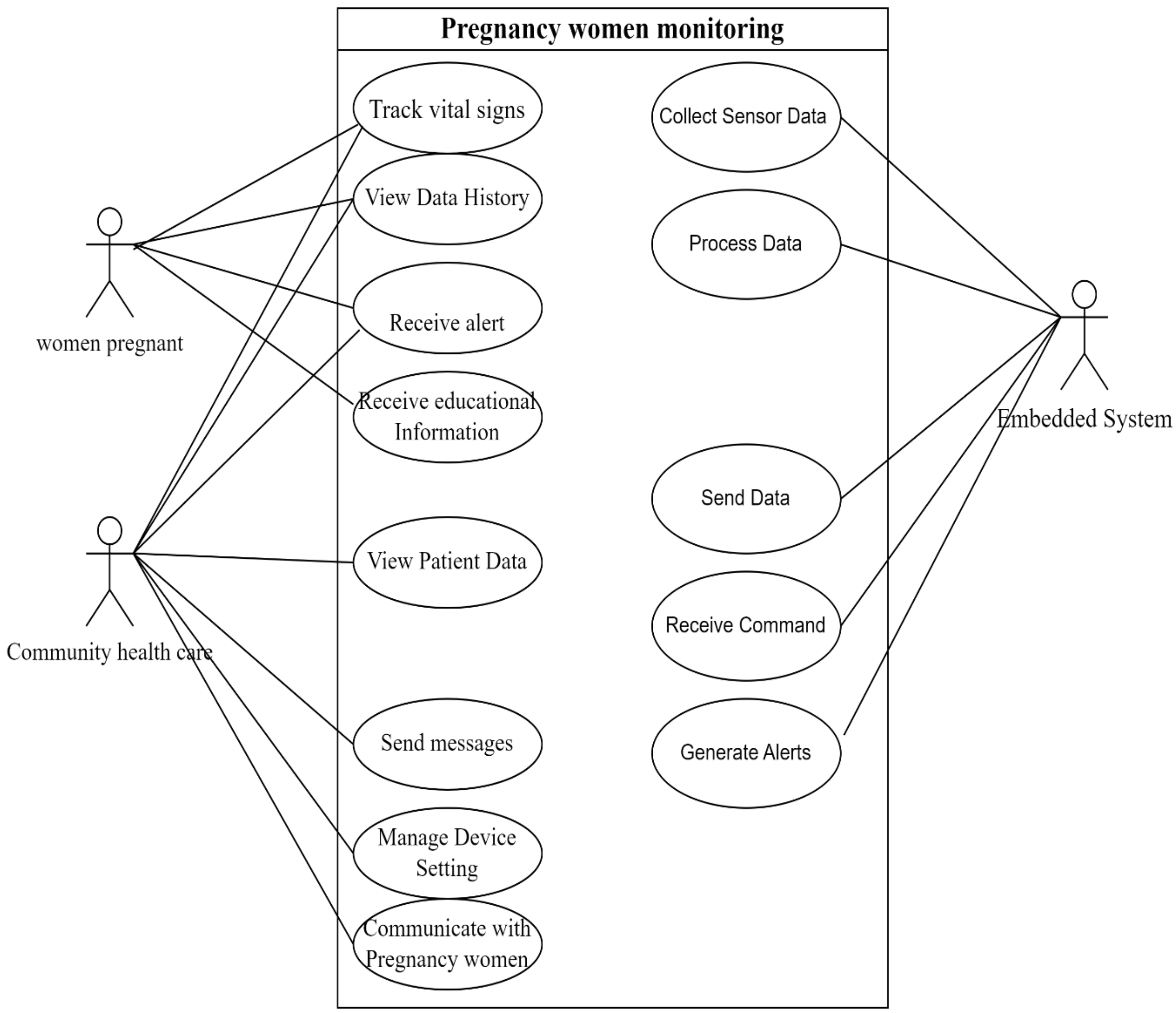


Figure 3. 10: The system use case Diagram

CHAPTER 4. RESULTS AND DISCUSSION

The chapter explores the technical framework of a real-time monitoring device for pregnant women in Rwanda. Results include data from prototype testing and user feedback, demonstrating the device's effectiveness and usability in rural healthcare. The analysis discusses implications for maternal healthcare, emphasizing scalability and future development opportunities.

4.1. Designed System

4.1.1 The System Prototype

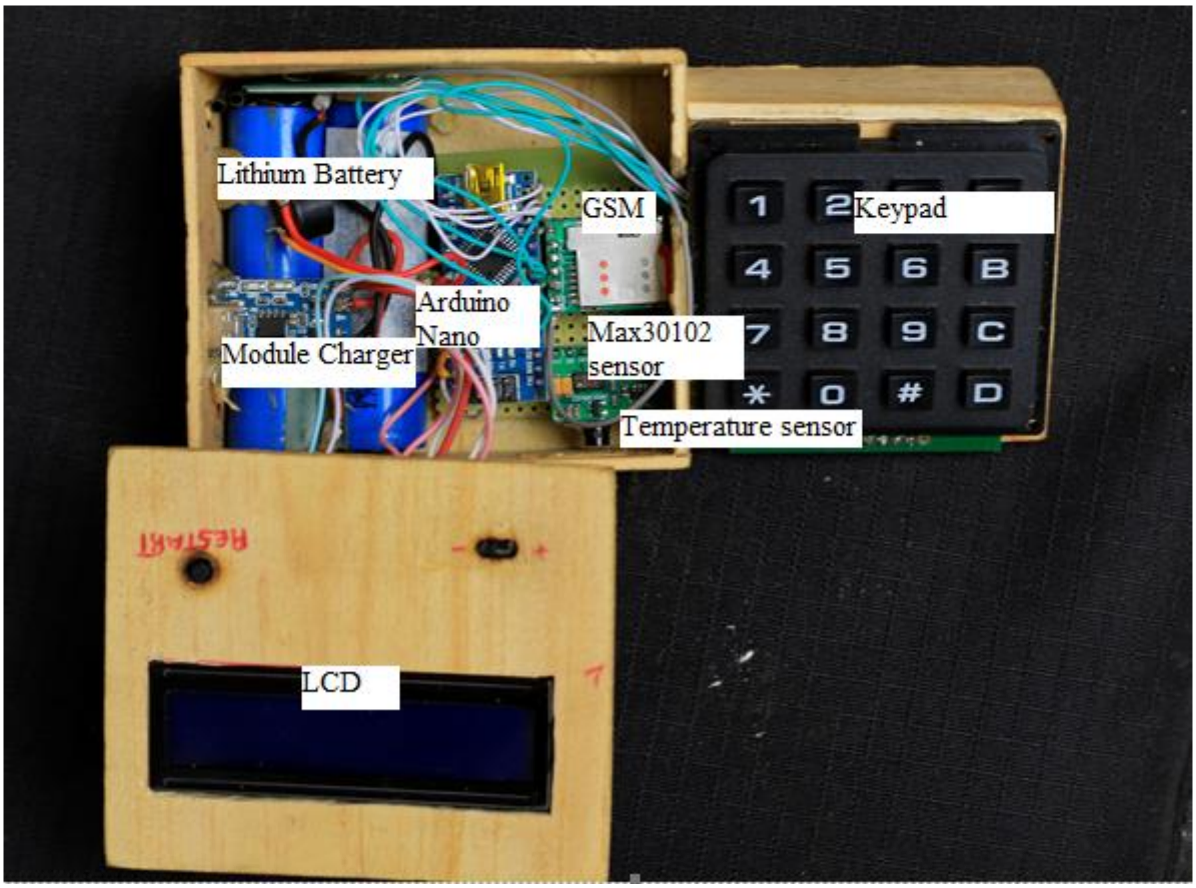


Figure 4: 1: System circuit

The circuit of the real-time monitoring device includes interconnected components essential for its functionality. A lithium battery powers the device, connected to a module charger for recharging. The Arduino Nano acts as the central controller, managing data flow between components such as the GSM module, the Max30102 sensor, the temperature sensor, and the LCD screen with a keypad for user input. The GSM module enables communication for data transmission to the mobile phone. The Max30102 sensor measures heart rate and SPO2, while the temperature sensor monitors body temperature. These sensor readings are displayed on the LCD screen and this system keypad could be used for entering the number of a pregnant mother, which may be linked to specific medical records. Overall, this circuit design facilitates real-time monitoring and communication functionalities.

4.1.2. Simulation Model

In the system for designing a smart real-time monitoring device for pregnant women, the EasyEDA simulation model is utilized to anticipate the results of the system. This simulation tool aids in obtaining data on pregnant women, the system is composed of Arduino Nano, a Global system for mobile communication, and heartbeat sensor, SPO2 sensor, temperature sensor, module charger, and lithium batteries. Which is then displayed on the mobile phone and LCD.

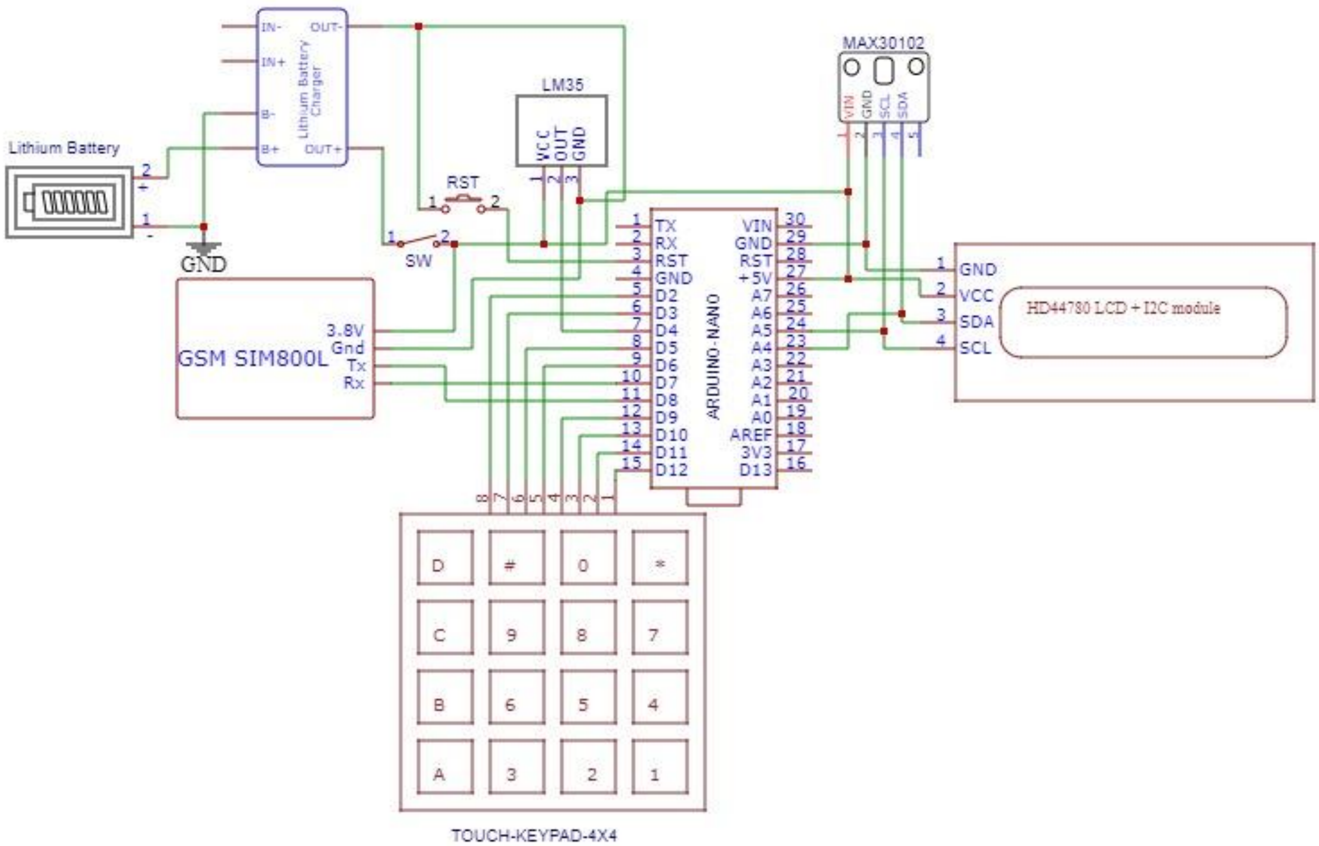


Figure 4: 2: indicates a prototype system consisting of all components connected using the Easyeda circuit simulator

4.2. Data displayed on LCD

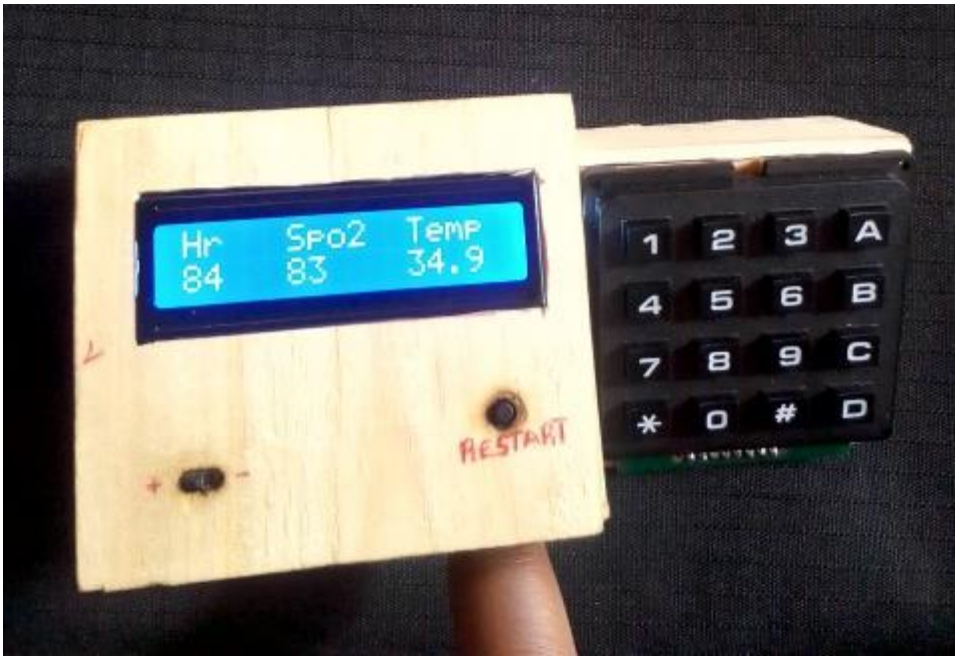


Figure 4: 3: Data displayed on LCD

The system collects health data from pregnant women, including heart rate, temperature, and SpO_2 levels, and displays this information on the LCD. Table 4.1 summarizes the collected data from various women who participated in the study.

Table 4. 1: Demographic and health data of pregnant women

ID	Age (Years)	Trimester	Heart Rate (bpm)	Temperature (°C)	SpO2 (%)	Alert
01	24	2nd	75	37.0	98	Normal
02	31	3rd	85	37.4	96	Normal
03	28	1st	95	38.0	92	Abnormal
04	22	3rd	70	36.8	99	Normal
05	30	2nd	80	37.2	95	Abnormal
06	26	1st	77	37.1	97	Normal
07	35	2nd	66	36.8	98	Normal
08	25	3rd	81	36.2	96	Normal
09	37	3st	110	37.0	93	Normal
10	22	1st	70	37.6	95	Abnormal

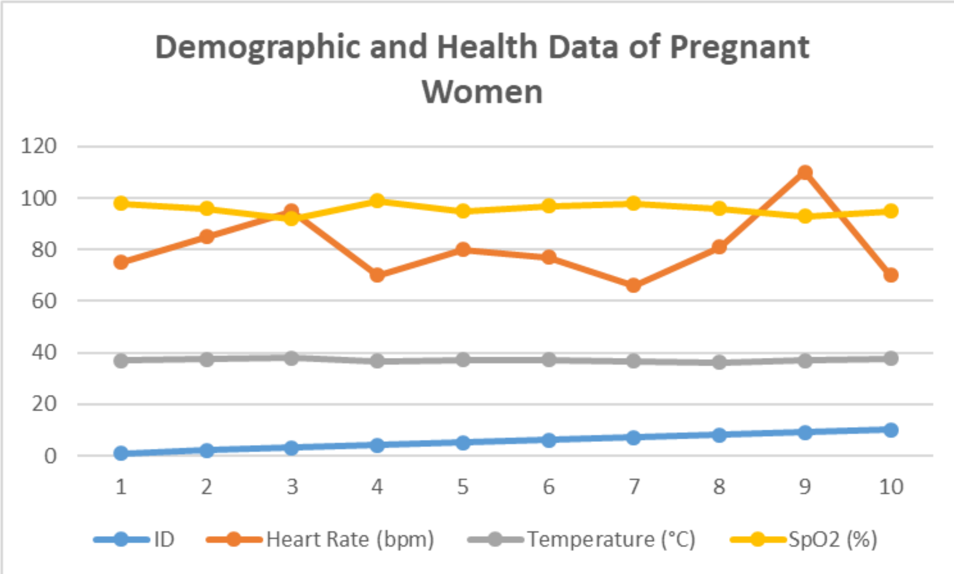


Figure 4: 4: Result for women pregnant in rural Rwanda

Figure 4.4 highlights the data collected from pregnant women across different trimesters, focusing on heart rate, body temperature, and oxygen saturation (SpO_2), with corresponding health alerts categorized as normal or abnormal.

Seven out of the ten participants are classified as normal, with stable vital signs falling within the expected ranges. Their heart rates range from 66 to 110 bpm, temperatures from 36.2°C to 37.6°C, and SpO_2 levels of 93% or higher. However, three participants exhibit abnormal readings.

- One woman in the first trimester shows a heart rate of 95 bpm, an elevated temperature of 38.0°C, and a SpO_2 level of 92%, which could indicate possible health concerns.
- Another participant in the second trimester has a normal heart rate and temperature but a slightly lower SpO_2 level of 95%, suggesting the need for further observation.
- The third abnormal case presents a higher temperature of 37.6°C, despite other readings being within the normal range.

These results highlight potential health risks and emphasize the importance of continuous monitoring for early detection and intervention.

4.3. Device Testing Results and Accuracy

4.3.1. Temperature Measurement Accuracy

Table 4. 2: temperature accuracy

ID	Actual Temperature (°C)	Device Measured Temperature (°C)	Error (%)
01	36.7	36.5	0.55%
02	37.1	37.0	0.27%
03	36.5	36.4	0.27%

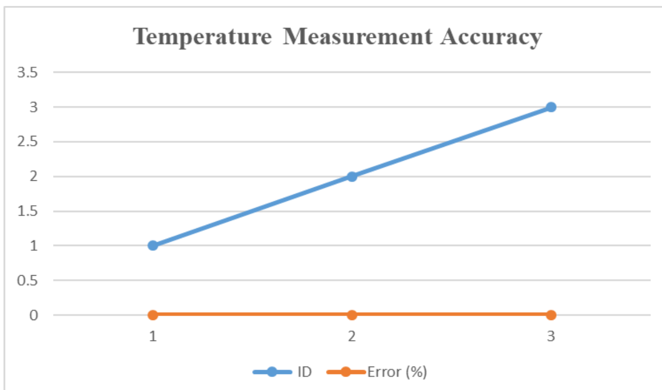


Figure 4: 5: Temperature measurement accuracy

Figure 4:5 The temperature measurement by the device shows minimal error, with an average deviation of less than 1%. This high accuracy enhances the device's reliability in detecting potential health risks related to abnormal temperature variations in pregnant women.

4.3.2. Heart rate Measurement Accuracy

Table 4. 3: BPM Accuracy

ID	Actual Heart Rate (BPM)	Device Measured Heart Rate (BPM)	Error (%)
01	78	80	2.56%
02	85	84	1.18%
03	90	89	1.11%

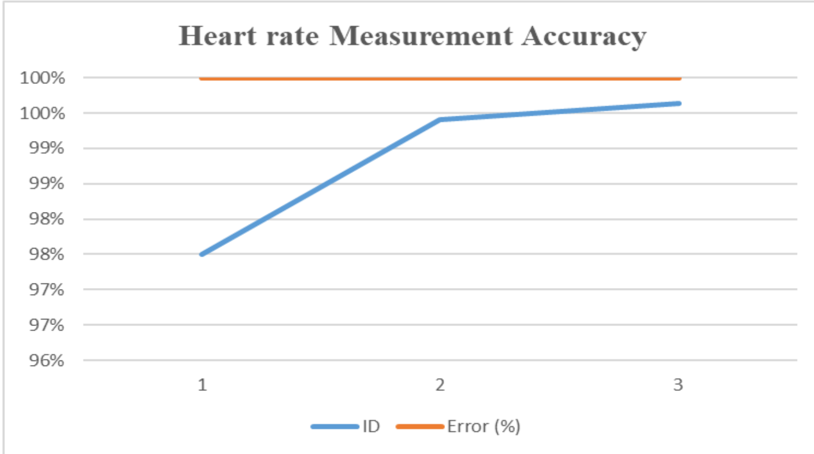


Figure 4: 6 Heart rate measurement accuracy

The results show that the device's heart rate measurement closely matches the actual heart rate values, with a low average error percentage of around 1.5%. This indicates the device performs reliably for heart rate monitoring, an essential feature for ensuring the health of pregnant women.

4.3.3. Oxygen Saturation (SpO2) Measurement Accuracy

ID	Actual SpO2 (%)	Device Measured SpO2 (%)	Error (%)
01	98	97	1.02%
02	96	95	1.04%
03	99	98	1.01%

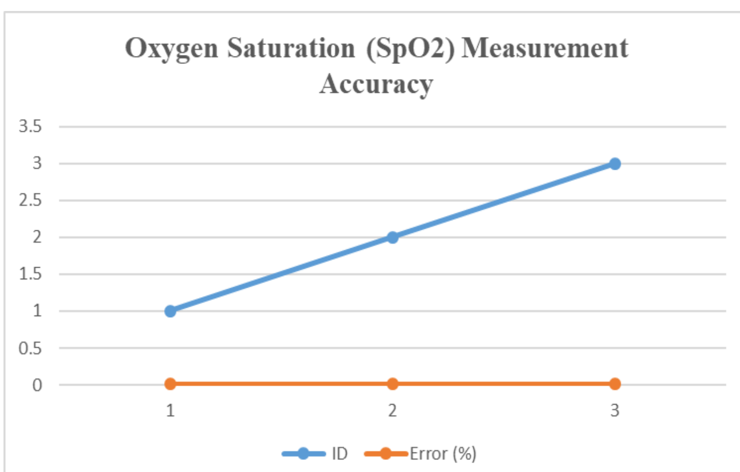


Figure 4: 7: Spo2 measurement accuracy

Figure 4:7 the device showed an average error rate of 1.02% when measuring oxygen saturation. This level of accuracy is suitable for early warning signs, making it a viable tool for real-time monitoring of pregnant women in rural areas where access to medical equipment is limited.

4.4. Summary

The chapter presents the design and evaluation of a real-time monitoring device for pregnant women in Rwanda, emphasizing its effectiveness and usability in rural healthcare settings. The device, powered by a lithium battery and controlled by an Arduino Nano, integrates various sensors to monitor vital signs, including heart rate, body temperature, and oxygen saturation (SpO_2). The collected data is displayed on an LCD and can be transmitted to mobile phones via a GSM module, allowing for real-time health monitoring. The results of prototype testing indicate that the device is reliable, with minimal error rates in temperature (less than 1%), heart rate (approximately 1.5%), and SpO_2 (around 1.02%). These findings highlight the device's potential for early detection of health issues, emphasizing the need for continuous monitoring in rural areas where access to healthcare is limited. Overall, the chapter discusses the implications for maternal healthcare, including scalability and future development opportunities.

4.3. Normal vital signals in pregnancy

Table 4. 4: Normal range parameters for each trimester

Vital sign	**First trimester**	**Second trimester**	**Third trimester**
Temperature	35.55 to 37.51	35.35 to 37.37	35.37 to 37.35
Heart Rate	63.1 to 105.2	67.4 to 112.5	64.5 to 113.8
Oxygen saturation SpO2	94.3 to 99.4	92.9 to 99.3	93.4 to 98.5

4.5. Comparison between Existing Systems to New System for Pregnant Women Monitoring Device

Table 4. 5: Comparison between Existing Systems to New Systems.

Existing System	**New System for Pregnant Women Monitoring**
Hospital check-up at least 4 times.	Real-time monitoring of portable devices check-up anywhere anytime)
Limited due to distance from health centers	Designed for rural areas with limited access to healthcare facilities.
Write on hard copy	Utilizes GSM module for data transmission
Data left to the health centers	Secure data storage on your mobile phone.
The current system consumes time.	The new system saves time.

CHAPTER 5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The study conducted in rural Rwanda highlights the challenges faced by pregnant women in accessing timely healthcare. The research focused on understanding these challenges and proposing a smart real-time monitoring device to address them. Through interviews and data analysis, it was found that many pregnant women live far from health centers, making it difficult for them to receive early pregnancy check-ups. However, there is a strong interest among women in receiving information about their pregnancies and using technology for health monitoring.

The proposed system consists of sensors for monitoring vital parameters, an Arduino for data processing, an LCD for displaying information, and a GSM module for transmitting data to mobile phones. The system aims to provide real-time health monitoring for pregnant women, enabling them to track their health status and receive timely alerts if any parameter is abnormal. The system is low-cost, low-power, secure, efficient, and easy to use.

5.2. Recommendation and Future Work

The study highlights the potential of the smart real-time monitoring device to enhance maternal healthcare in rural Rwanda. To fully realize this potential, several recommendations are proposed. First, the device should be implemented in rural areas to improve healthcare access for pregnant women. Training programs for community health workers can ensure effective device utilization. Second, the design of the device should focus on being easy to use, especially for women who may not be familiar with technology, with clear instructions and help available. Third, connecting the device with the current healthcare system is very important for using the data it collects effectively. Fourth, it's important to keep checking and evaluating the device to see how it is helping improve the health of mothers. Finally, the system should be scalable for easy expansion to other regions and countries facing similar healthcare challenges. These recommendations, along with the potential for future work in enhancing the device's features and functionalities, if implemented effectively, can improve maternal health outcomes in rural Rwanda. Future work could focus on improving the device's accuracy and reliability, expanding its functionality to include additional health parameters, and exploring ways to integrate it with other healthcare technologies for comprehensive maternal care.

REFERENCES

[1] WHO, UNICEF UNFPA, and WORLD BANK GROUP and UNDESA/Population Division, *Trends in maternal mortality 2000 to 2020: estimates*. 2023. [Online]. Available: https://www.who.int/reproductivehealth/publications/maternal-mortality-2000-2017/en/

[2] World health organization, “Maternal mortality,” *2023*.

[3] H. Survey, “Rwanda,” 2019.

[4] NISR.2019-2020, *National Institute o f Statistics and Research.Rwanda Demographic and health survey*. 2020.

[5] B. Priyanka, V. M. Kalaivanan, R. A. Pavish, and M. Kanageshwaran, “IOT Based Pregnancy Women Health Monitoring System for Prenatal Care,” *2021 7th Int. Conf. Adv. Comput. Commun. Syst. ICACCS 2021*, pp. 1264–1269, 2021, doi: 10.1109/ICACCS51430.2021.9441677.

[6] S. Ansari and M. B. Ansari, “Smart Health Monitoring System for Pregnant Women,” *Int. J. Eng. Adv. Technol.*, vol. 9, no. 4, pp. 923–926, 2020, doi: 10.35940/ijeat.d7114.049420.

[7] A. R M, “An Application for Monitoring Pregnant Women Using IOT,” *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 10, no. 7, pp. 3523–3528, 2022, doi: 10.22214/ijraset.2022.45793.

[8] I. Sheet, “Maternal Cause”.

[9] A. M. Speciale and M. Freytsis, “MHealth for Midwives: A Call to Action,” *J. Midwifery Women’s Heal.*, vol. 58, no. 1, pp. 76–82, 2013, doi: 10.1111/j.1542-2011.2012.00243.x.

[10] R. Kosaraju, “How Mobile Devices Are Transforming Healthcare,” *Acad. Lett.*, no. 18, pp. 1–14, 2021, doi: 10.20935/al2687.

[11] V. Mivumbi, C. E. Rouse, S. Little, and J. Greenberg, “Maternal Mortality in Rwanda [13I],” *Obstet. Gynecol.*, vol. 127, no. Supplement 1, pp. 76S-77S, 2016, doi: 10.1097/01.aog.0000483717.91652.db.

[12] I. Efrem, “Developing a mobile application supporting parents’ activities during pregnancy,” pp. 1–78, 2019, [Online]. Available: http://dspace.uib.no/bitstream/handle/1956/20847/Master-Thesis-Igor-Efrem.pdf?sequence=1&isAllowed=y

[13] H. Wang and J. Liu, “Mobile phone based health care technology,” *Recent Pat. Biomed. Eng.*, vol. 2, no. 1, pp. 15–21, 2009, doi: 10.2174/1874764710902010015.

[14] A. Haleem, M. Javaid, R. P. Singh, and R. Suman, “Telemedicine for healthcare: Capabilities, features, barriers, and applications,” *Sensors Int.*, vol. 2, no. July, p. 100117, 2021, doi: 10.1016/j.sintl.2021.100117.

[15] N. Gous, J. Takle, A. Oppenheimer, and A. Schooley, “Racing for results: lessons learnt in improving the efficiency of HIV viral load and early infant diagnosis result delivery from laboratory to clinic,” *Expert Rev. Mol. Diagn.*, vol. 18, no. 9, pp. 789–795, 2018, doi: 10.1080/14737159.2018.1503951.

[16] N. V. Lemay, T. Sullivan, B. Jumbe, and C. P. Perry, “Reaching remote health workers in Malawi: Baseline assessment of a pilot mhealth intervention,” *J. Health Commun.*, vol. 17, no. SUPPL. 1, pp. 105–117, 2012, doi: 10.1080/10810730.2011.649106.

[17] KDHS, “Demographic and Health Survey: Key Indicators Report,” *Kenya Bur. Stat.*, vol. 1, no. 1, pp. 1–23, 2023.

[18] P. Mwendwa, “Assessing the fit of RapidSMS for maternal and new-born health: perspectives of community health workers in rural Rwanda,” *Dev. Pract.*, vol. 26, no. 1, pp. 38–51, 2016, doi: 10.1080/09614524.2016.1112769.

[19] E. Bossman, M. A. Johansen, and P. Zanaboni, “mHealth interventions to reduce maternal and child mortality in Sub-Saharan Africa and Southern Asia: A systematic literature

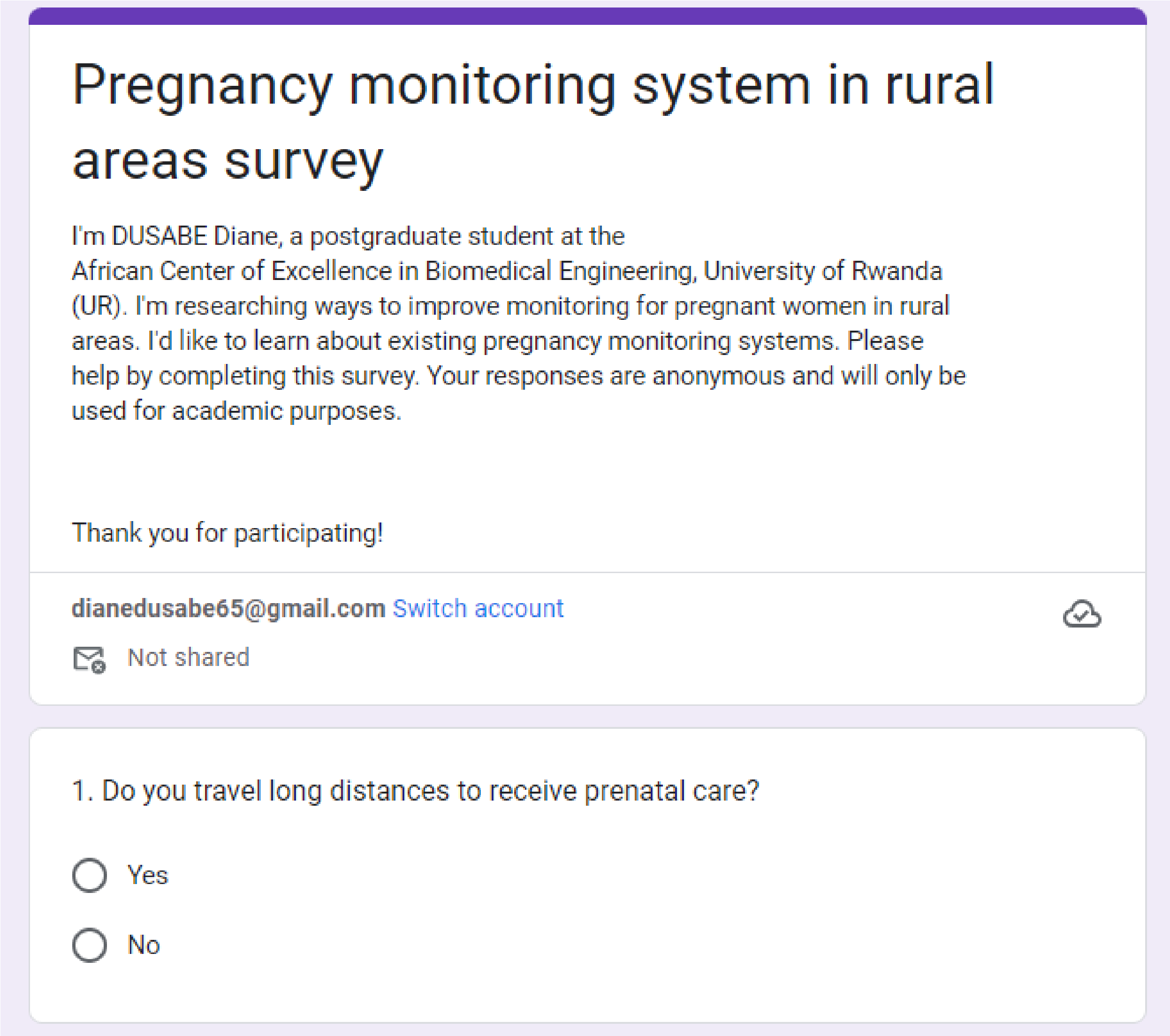
review," *Front. Glob. Women's Heal.*, vol. 3, 2022, doi: 10.3389/fgwh.2022.942146.
[20] F. Okonofua *et al.*, "Effect of a multifaceted intervention on the utilisation of primary health for maternal and child health care in rural Nigeria: A quasi-experimental study," *BMJ Open*, vol. 12, no. 2, pp. 1–11, 2022, doi: 10.1136/bmjopen-2021-049499.
[21] N. Aminisasi, "Cervical Screening in New South Wales and Its Relationship to Country of Birth and Socioeconomic Status," no. August, p. ii, 2011.
[22] A. Jesus and M. J. Gomes, "Web 2.0 tools in biomedical education: Limitations and possibilities," *Learn. Manag. Syst. Instr. Des. Best Pract. Online Educ.*, no. April 2013, pp. 208–231, 2013, doi: 10.4018/978-1-4666-3930-0.ch011.
[23] Ü. Kotta, P. Kotta, S. Nõmm, and M. Tõnso, "Irreducibility conditions for continuous-time multi-input multi-output nonlinear systems," *9th Int. Conf. Control. Autom. Robot. Vision, 2006, ICARCV '06*, pp. 1–8, 2006, doi: 10.1109/ICARCV.2006.345249.
[24] A. Musiimenta, W. Tumuhimbise, G. Mugyenyi, J. Katusiime, E. Atukunda, and N. Pinkwart, "A Mobile Phone-based Multimedia Application Could Improve Maternal Health in Rural Southwestern Uganda: Mixed Methods Study," *Online J. Public Health Inform.*, vol. 12, no. 1, pp. 1–17, 2020, doi: 10.5210/ojphi.v12i1.10557.
[25] S. Lund *et al.*, "Mobile phone intervention reduces perinatal mortality in zanzibar: Secondary outcomes of a cluster randomized controlled trial," *JMIR mHealth uHealth*, vol. 2, no. 1, 2014, doi: 10.2196/mhealth.2941.
[26] F. Ngabo *et al.*, "Designing and implementing an innovative SMS-based alert system (RapidSMS-MCH) to monitor pregnancy and reduce maternal and child deaths in Rwanda," *Pan Afr. Med. J.*, vol. 13, pp. 1–15, 2012.
[27] H. Allahem and S. Sampalli, "Framework to monitor pregnant women with a high risk of premature labour using sensor networks," *Proc. IM 2017 - 2017 IFIP/IEEE Int. Symp. Integr. Netw. Serv. Manag.*, pp. 1178–1181, 2017, doi: 10.23919/INM.2017.7987458.
[28] J. Ø. Odland and L. Arbour, "Maternal and child health," *Heal. Transitions Arct. Popul.*, pp. 379–402, 2008.
[29] A. Microcontroller, "Target Areas," *Lancet*, vol. 300, no. 7770, p. 222, 1972, doi: 10.1016/S0140-6736(72)91649-2.
[30] "The Global System for Mobile Communications," *Protoc. High-Efficiency Wirel. Networks*, pp. 17–44, 2005, doi: 10.1007/0-306-47795-5_2.
[31] L. Kencl, "Global System for Mobile Communication (GSM) Definition 1 . Introduction : The Evolution of Mobile Telephone Systems," pp. 1–19, 1982.
[32] M. N. Cramer, D. Gagnon, O. Laitano, and C. G. Crandall, "Human Temperature Regulation Under Heat Stress in Health, Disease, and Injury," *Physiol. Rev.*, vol. 102, no. 4, pp. 1907–1989, 2022, doi: 10.1152/PHYSREV.00047.2021.
[33] A. Bansal, V. Athavale, K. Kaur, and A. Garg, "IoT Enabled Prenatal Health Monitoring System for Pregnant Women," 2023, doi: 10.4108/eai.24-3-2022.2319150.
[34] F. C. Baker, F. Siboza, and A. Fuller, "Temperature regulation in women: Effects of the menstrual cycle," *Temperature*, vol. 7, no. 3, pp. 226–262, 2020, doi: 10.1080/23328940.2020.1735927.
[35] V. R. Parihar, A. Y. Tonge, and P. D. Ganorkar, "Heartbeat and Temperature Monitoring System for Remote Patients using Arduino," *Int. J. Adv. Eng. Res. Sci.*, vol. 4, no. 5, pp. 55–58, 2017, doi: 10.22161/ijaers.4.5.10.
[36] Maxim Integrated, "Pulse Oximeter and Heart-Rate Sensor IC for Wearable Health," *Lect. Notes Energy*, vol. 38, pp. 1–29, 2014, [Online]. Available: www.maximintegrated.com
[37] R. Strogonovs, "Implementing pulse oximeter using MAX30100," no. 3, pp. 1–20, 2017.
[38] H. D. Abruña, Y. Kiya, and J. C. Henderson, "Batteries and electrochemical capacitors," *Phys. Today*, vol. 61, no. 12, pp. 43–47, 2008, doi: 10.1063/1.3047681.
[39] L. Lu and H. Nagai, *Lithium-ion Batteries - Thin Film for Energy Materials and Devices*.

2019. doi: 10.5772/intechopen.73346.
[40] R. Rittenberry, “Hands-on technology.,” *Occup. Health Saf.*, vol. 74, no. 2, p. 24, 2005.
[41] M. Fezari and A. A. D. Al Zaytoona, “Integrated Development Environment ‘IDE’ For Arduino Integrated Development Environment ‘IDE’ For Arduino Introduction to Arduino IDE,” *ResearchGate*, no. October, 2018, [Online]. Available: https://www.researchgate.net/publication/328615543

APPENDICES

Appendix 1:

The questionnaire sample



Pregnancy monitoring system in rural areas survey

I'm DUSABE Diane, a postgraduate student at the
African Center of Excellence in Biomedical Engineering, University of Rwanda
(UR). I'm researching ways to improve monitoring for pregnant women in rural
areas. I'd like to learn about existing pregnancy monitoring systems. Please
help by completing this survey. Your responses are anonymous and will only be
used for academic purposes.

Thank you for participating!

dianedusabe65@gmail.com Switch account

Not shared

1. Do you travel long distances to receive prenatal care?

- Yes
- No

2. How often do you go for check-ups with a healthcare provider during pregnancy?

- ◯ no one
- ◯ once
- ◯ twice
- ◯ three times
- ◯ four times or above

3. Do you think the number of your check-ups is enough?

- ◯ Yes
- ◯ No
- ◯ Maybe

4. Do you face challenges accessing healthcare due to your village's location?

- ◯ Yes
- ◯ No

If your answer is YES why?

- ◯ Health facility is far
- ◯ problem of financy
- ◯ Disability
- ◯ Other

5. Would you feel more confident in your pregnancy with access to real-time information?

- ◯ Yes
- ◯ No

6. Would you prefer a smart monitoring device that can function without internet?

- ◯ Yes
- ◯ No
- ◯ Maybe

7. Are you currently receiving prenatal care from a healthcare provider in your village?

- ◯ Yes
- ◯ No
- ◯ Prefer not to answer

8. Have you used technology to monitor your health during pregnancy in your village?

- ◯ Yes
- ◯ No

If your answer is YES ,which sensor did you use?

- Temperature sensor
- Blood pressure sensor
- SPo2 sensor
- Heartbeat sensor
- All sensor

9. Would you be interested in using a smart monitoring device to track your vital signs during pregnancy in your village?

- Yes
- No
- Prefer not to answer

10. How concerned are you about the privacy and security of your health data collected by the monitoring device?

- Very concerned
- Somewhat concerned
- Not very concerned
- Not concerned at all

Submit

Clear form

Appendix 2:

The system code

```
#include <MAX3010x.h>
#include "filters.h"
#include <OneWire.h>
#include <DallasTemperature.h>
#include <SoftwareSerial.h>
#include <Keypad.h>
#include <LCD_I2C.h>

#define ONE_WIRE_BUS 4
OneWire oneWire(ONE_WIRE_BUS);
DallasTemperature sensors(&oneWire);
SoftwareSerial gsmSerial(7, 8);
LCD_I2C lcd(0x27, 16, 2);

#include <Keypad.h>

#define ROWS 4
#define COLS 4

// Parameters
const char kp4x4Keys[ROWS][COLS] = {
  { '1', '2', '3', '+' },
  { '4', '5', '6', 'B' },
  { '7', '8', '9', 'C' },
  { '*', '0', '#', 'D' }
};
byte rowKp4x4Pin[4] = { 9, 10, 11, 12 };
byte colKp4x4Pin[4] = { 2, 3, 5, 6 };

Keypad kp4x4 = Keypad(makeKeymap(kp4x4Keys),
```

```
char customKey;
String enteredNumber = "";

#define REPORTING_PERIOD_MS 4000
uint32_t tsLastReport = 0;

MAX30102 sensor;
const auto kSamplingRate = sensor.SAMPLING_RAT
const float kSamplingFrequency = 400.0;
int bpm;
float spo2;
float tempC;
int gsrValues;
int diastole;
bool smsSent = false;
// Finger Detection Threshold and Cooldown
const unsigned long kFingerThreshold = 10000;
const unsigned int kFingerCooldownMs = 500;

// Edge Detection Threshold (decrease for MAX3
const float kEdgeThreshold = -2000.0;

// Filters
const float kLowPassCutoff = 5.0;
const float kHighPassCutoff = 0.5;

// Averaging
const bool kEnableAveraging = true;
const int kAveragingSamples = 5;
```

```
const int kAveragingSamples = 5;
const int kSampleThreshold = 5;

const int buttonPin = 8;
int buttonState = 0;
int lastButtonState = 0;
int State = 1;
int f_value = 0;
int average_bpm;
int average_r;
int average_spo2;

#define PHONE_NUMBER_MAX_LENGTH 12
char phoneNumber[PHONE_NUMBER_MAX_LENGTH + 1];
int phoneNumberIndex = 0;

// Counter for threshold detections
int thresholdCount = 0;

void setup() {
  Serial.begin(115200);
  gsmSerial.begin(9600);
  sensors.begin();
  lcd.begin();
  lcd.backlight();
  delay(1000);

  if (sensor.begin() && sensor.setSamplingRate
    Serial.println("Sensor initialized");
  } else {
```

```
    } else {
      sendSMSAlert();
      smsSent = true;  // Mark SMS as sent
      Serial.println("SMS sent successfully");
      thresholdCount = 0;  // Reset threshold counter if val
      smsSent = false;     // Reset SMS sent status
    }
    // Check if the threshold has been exceeded 5 times
    if (thresholdCount >= 5 && !smsSent) {
      if ((tempC < 35.5) || (tempC > 37.3) || (bpm < 63.1) |
        // thresholdCount++;
        sendSMSAlert1();
        smsSent = true;  // Mark SMS as sent
        Serial.println("SMS sent successfully");
        thresholdCount = 0;
        smsSent = false;
      }
    }
    Serial.println(thresholdCount);

    tsLastReport = millis();
  }
  crossed = false;
  last_heartbeat = crossed_time;


_diff = current_diff;
```

```
  gsmSerial.println("AT+CMGF=1");  // Configuring TEXT mode
  updateSerial();
  gsmSerial.println("AT+CMGS=\"" + enteredNumber + "\"");  //change Z
  updateSerial();
  gsmSerial.print("Hr:" + String(bpm) + ", TEMP:" + String(tempC) + "
  updateSerial();
  gsmSerial.write(26);
}

void sendSMSAlert1() {
  // Serial.println("SMS sent: You are Normal");

  gsmSerial.println("AT+CMGF=1");  // Configuring TEXT mode
  updateSerial();
  gsmSerial.println("AT+CMGS=\"" + enteredNumber + "\"");  //change Z
  updateSerial();
  gsmSerial.print("Hr:" + String(bpm) + ", TEMP:" + String(tempC) + "
  updateSerial();
  gsmSerial.write(26);
}
void updateSerial() {
  delay(500);
  while (Serial.available()) {
    gsmSerial.write(Serial.read());  //Forward what Serial received t
  }
  while (gsmSerial.available()) {
    Serial.write(gsmSerial.read());  //Forward what Software Serial r
  }
}
```