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

DESIGN AND DEVELOPMENT OF A PORTABLE MICROFLUIDIC DEVICE FOR DIABETES DETECTION.

By:

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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.

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Dr. Morufu Olusola Ibitoye.

DECLARATION

I, TUYISENGE SOLANGE declare that this dissertation entitled "**DESIGN AND DEVELOPMENT OF A PORTABLE MICROFLUIDIC DEVICE FOR DIABETES DETECTION**" is my original work and has not been submitted for any other degree or professional qualification.

Student Name: **TUYISENGE SOLANGE**

Student Reference Number: **221031672**

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Date: _____

CERTIFICATE

This is to certify that the project entitled "**DESIGN AND DEVELOPMENT OF A PORTABLE MICROFLUIDIC DEVICE FOR DIABETES DETECTION**" is a record of original work done by **TUYISENGE SOLANGE** (Reference number: **221031672**), a Master's Degree student in Biomedical Engineering.

This work has been submitted under the guidance of Dr. Jean Felix Mukerabigwi and Dr. Morufu Olusola Ibitoye.

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ABSTRACT

Diabetes is a chronic, metabolic disease characterized by elevated levels of blood glucose which leads over time to serious damage to the heart, blood vessels, eyes, kidneys and nerves. These problems can be avoided with proper diabetes management and early detection. The large number of populations especially in remote areas face the challenges of knowing early the disease before symptoms develop. To address challenges associated with traditional diagnostic methods, such as time-consuming processes, cost, complexity and limited accessibility, portable microfluidic devices have significantly enhanced the delivery of healthcare services, particularly in remote or resource-limited settings to automatically detect and monitor glucose levels in urine and blood for providing rapid and accurate results. This thesis explores the utilization of Rasberry Pi microcontroller with microfluidic platforms, GSM, to develop a sensitive, accurate and cost-effective solution for frequent diabetes detection and monitoring in home environments and utilized by those who are not healthcare professionals. This research combines a number of elements including microchannels, Biosensors, and data processing modules into a portable and approachable platform. The device uses small samples of urine, blood and sensing techniques. Our approach began with utilizing a 3D printer, employing Polydimethylsiloxane (PDMS), to design and prototype a microfluidic chip. Enhancing its functionality, we seamlessly integrated a biosensor capable of detecting diabetes-related biomarkers. Finally, we tested a device with different samples for analyzing the performance of the device. The outcomes of this study significantly contribute to mitigating risks associated with complications by enabling the convenient monitoring of blood glucose levels at home, empowering non-medically trained individuals. Moreover, our research offers promising avenues for reducing healthcare expenditures by alleviating the necessity for frequent hospital visits for blood glucose tests.

Keywords: Microfluidic device; Diabetes; Non-communicable disease; Point of care Diagnostics.

LIST OF ACRONYMS

1. BGL - Blood Glucose Levels
2. COMSOL - COMSOL Multiphysics (simulation software)
3. DM - Diabetes Mellitus
4. ELISA - Enzyme-Linked Immunosorbent Assay
5. GDP - Gross Domestic Product
6. NFC - Near Field Communication
7. NCD - Non-Communicable Disease
8. LMIC - Low- and Middle-Income Countries
9. PDMS - Polydimethylsiloxane
10. POC - Point-of-Care
11. SMS - Short Message Service

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CHAPTER 1: GENERAL INTRODUCTION

1.1 Introduction

Diabetes mellitus commonly referred to as diabetes, is a group of diseases that affect how the body uses blood sugar known as glucose. It is a non-communicable disease and chronic disease caused by inherited and/or acquired deficiency in the production of insulin by the pancreas, or by the ineffectiveness of the insulin produced [1]. Non-communicable diseases claim about 41 million deaths each year, equivalent to 71% of global deaths, of which 80% is in low and middle income countries [2]. This is due to an increase in associated risk factors such as the use of tobacco, an increase in the consumption of fats, sugar, alcohol, animal products, age, family history, and diseases of the pancreas.

In a study conducted by World Health Organization, between 2000 and 2019, there was a 3% increase in age-standardized mortality rates from diabetes. In lower-middle-income countries, the mortality rate due to diabetes increased 13%.In Rwanda, the national prevalence of diabetes in rural and urban was 7.5 and 9.7%, respectively among 15–64 years [3]. The increase in blood glucose levels cause chronic damage to vessels and nerves, resulting in the injury of multiple organs and even acute coma and death. The glucose is the main type of sugar in the blood that comes from the foods. It is the major source of energy for the body's functions. Without insulin glucose cannot get into cells and so it stays in the bloodstream. Hypoglycaemia is a low blood glucose level occurring in a person with diabetes mellitus. On the contrary, Hyperglycaemia is the technical term for high blood glucose because of too little insulin or when the body is unable to use insulin properly.The portable microfluidic device for diabetes detection is the most promising platform for urine analysis and blood analysis due to their characteristics in handling small volumes of samples [4]. The device is also known as lab-on-a-chip, and has the potential to detect and diagnose diseases in places with limited resources and even at home. It can be used by people who are not medical experts with good performance. The device is affordable and can be put together easily using readily available components and 3D printing. As the demand for accessible healthcare increases, there is a growing interest in home-based diabetes detection. In this regard, incorporating healthcare providers or professionals can play a vital role in guiding individuals through the detection process, results interpreting and provision of necessary guidance or recommendations for objective clinical decision.

The current study outcomes are going to enhance healthcare accessibility, empower individuals to take charge of their health by self-monitoring of blood glucose levels (BGL) for patients who may lack the time or financial resources for routine medical test. This also has the potential to drive the development of user-friendly and affordable microfluidic devices for point-of-care diagnostics. This results from the current study could help to improve the lives of people living with diabetes [5].

1.2 Problem statement

Diabetes is a chronic health issue that, if undiagnosed or improperly managed, can have devastating effects. It is one of the top causes of death and disability globally. The increased mortality rate of diabetes due to the late detection of the disease is a challenge to the Rwandan population, The device proposed in this current study will be used to detect diabetes early before the manifestation of the diabetes symptoms. Many Rwandans face multiple barriers, including living in remote areas and financial constraints, which prevent them from seeking timely medical care. Moreover, existing technologies for diabetes detection are expensive, making them unaffordable for a significant portion of the population. Additionally, these technologies are often not user-friendly, making them difficult to use without specialized training. To address these challenges, the portable microfluid device aims to develop a portable microfluidic device for early diabetes detection, emphasizing its portability, affordability, and user-friendliness.
By overcoming these challenges, the designing of a portable microfluidic device for detecting diabetes at an early stage with its portability, affordability, and user-friendliness advantages by ultimately mitigating high risks associated with late diagnoses and revolutionizing the landscape of point-of-care diagnostics to enhance healthcare accessibility, and save time by providing a convenient testing solution that eliminates the need for extensive travel to healthcare facilities.

1.3 Research questions

Following are the main research questions for this study:

- How can the design of a portable microfluidic device for diabetes detection be optimized to balance user friendliness for Rwandan population?
- What fabrication techniques and processes are most suitable for developing a prototype of microfluidic device for diabetes detection?
- What are the potential challenges associated with the design and development of microfluidic device for diabetes detection?

1.4 Objectives

1.4.1 General objective

This research study aims to design a portable microfluidic device for diabetes detection that is affordable, portable and simple to use for everyone.

1.4.2 Specific objectives

To achieve the general objective of this project, the specific objectives are:

- To develop a conceptual design of the device
- To design a microfluidic chip using a 3D printer and polydimethylsiloxane (PDMS)
- To develop a prototype of the microfluidic device for diabetes detection
- To test the performance of the developed device using urine and blood samples

1.5 Scope of the study

This study is limited to the detection of diabetes within the Rwandan population by utilizing urine and blood samples. The study will primarily focus on the development and evaluation of a portable microfluidic device for diabetes detection in Rwanda with the design and prototyping of a microfluidic chip combined with integrated sensing elements tailored to detect diabetes related biomarkers and the use of simulation techniques to assess the device performance. The primary goal of this study is to provide a cost-effective and accessible solution for diabetes management, particularly in resource-limited settings and home environments in Rwanda.

1.6 The significance of the study

The significance of this study lies in the development of a portable microfluidic device for diabetes detection, which has the potential to revolutionize diabetes management. By offering convenient, cost-effective, and accessible monitoring solutions, this research study addresses a critical need in healthcare, particularly in resource-limited settings. It promises to enable individuals to manage their diabetes effectively, reduce healthcare costs, and promote early detection and prevention of

the clinical condition, ultimately contributing to the improved health outcomes and potentially serving as a model for healthcare innovation with global implications.

1.7 Thesis Organization

This research is organized as the following: Chapter One presents the introduction to the whole project of designing and development of the portable microfluidic device for diabetes detection, The Chapter Two discusses the literature review where information was presented about previous related researches on glucose sensors, Chapter Three discusses the research methodology, Chapter Four presents the project results from implementation. Chapter five discusses the results and findings of the research study and finally Chapter Six discusses challenges, recommendations and conclusions of the research study.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

Diabetes is a group of diseases that affect how the body uses blood sugar known as glucose. It is a non-communicable disease (NCD) and chronic disease caused by inherited or acquired deficiency in the production of insulin by the pancreas, or by the ineffectiveness of the insulin produced [1]. This deficiency damages many of the body systems, in particular the blood vessels and nerves. To prevent complications, patients are expected to perform self-monitoring of their blood glucose levels (BGL) [6].

2.1 Types of Microfluidic devices for detecting diabetes

2.1.1 Biological Fluid-Based Glucose Sensors

Glucose content in the body can be detected using various biological fluids or biofluids such as blood, sweat, urine, interstitial fluids, tears, breath, and saliva. In diabetic patients, glucose levels in other biofluids and blood are correlated to some degree. Moreover, their ease of production and collection have led to extensive research and development on biofluid-based glucose sensors, making the glucose level detection and monitoring process more patient-friendly. In the determination of glucose levels in patients, blood has been used for decades. Although the use of blood is accurate and selective, with the growing number of diabetic patients and the discomfort they face with invasive methods of blood sample collection, there has been an increased need for sophisticated, fast, and minimally invasive to non-invasive methods of sample collection. To address this issue, many researchers have been working on the development of sensors with capabilities to detect glucose in other biological fluids apart from blood sample [7]. The challenges with this technology involve low glucose concentrations in analytes such as saliva, tears and sweat, posing difficulties during correlation with blood glucose levels, a task that requires high sensitivity and lower detection limits for the devices that uses non blood samples for diabetes detection.

2.1.2 Smartphone-based electrochemical glucose monitoring system

Jie Xu et al., (2022) constructed a technology integrated in smartphones for sensitive detection of glucose. This method has been promoted as a controller, analyzer, displayer and sharer for rapid, and real-time point-of-care electrochemical glucose monitoring. When sensing glucose using electrochemical method, glucose is oxidized via glucose oxidase, glucose dehydrogenase or non-enzymatic catalysts, electrons are transferred on the electrode surface and an electrical signal is generated [7]. Glucose level in blood is one of the most reliable indicators for diabetes

monitoring. This study focused on smartphone based portable blood glucose monitoring in order to provide convenient, real-time and credible data for diabetes patients and clinics. The system included a smartphone, a portable electrochemical circuit board and a functional material modified glucose electrode. A smartphone was used to control the electrochemical module and display the detection result [8].

However, the challenges of this method include the unclear and disputable correlation between glucose levels in blood and in some biofluids which are secreted on body surface, as well as the requirement of a low detection range and high sensitivity because of the lower glucose concentration in non-blood-based samples.

2.1.3 Protein biomarker technique

The conventional detection method for protein biomarkers and analysis is an enzyme-linked immunosorbent assay (ELISA). It is a laboratory technique used to detect and quantify the presence of specific proteins, antibodies or antigens in a sample [9]. ELISA has several advantages, including its high sensitivity in detecting protein content, making it the gold standard method for protein identification and quantification. It has been successfully applied to detect various proteins and infectious pathogens, including viruses such as dengue, Zika, influenza and SARS-COV-2 virus. this detection method has limitations of its sensitivity for protein detection.

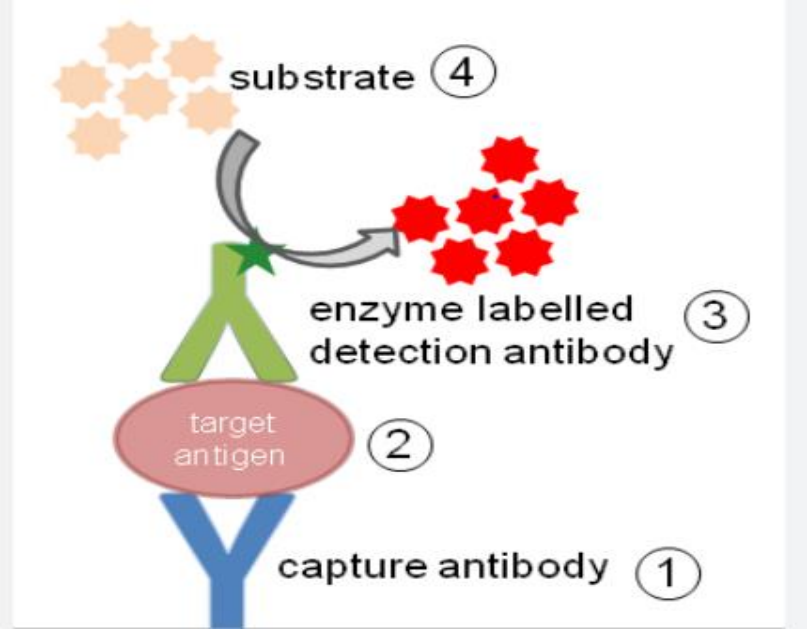

Figure 2. 1 ELISA method showing the steps numbered in order 1-4

2.1.4 Microfluidic Paper based analytical devices (µPADs)

Yetisen et al., (2021) worked on paper-based microfluidic point-of-care diagnostic devices(µPADs) to analyze various analytics in the human body, including urine, saliva, blood, tears, and other bodily or exocrine fluids. Paper-based microfluidics are the branch of microfluidics involving devices made out of paper, or other porous membranes, that wick fluids by capillary action [10]. Paper-based microfluidic devices have several advantages over conventional microfluidic devices including simpler fabrication, lower cost, easier disposal, and the ability to operate without pumps or other supporting equipment [11]. The most common application of paper-based microfluidic devices is in the development of point-of-care (POC) diagnostic devices, which could eliminate the need for costly and time-consuming laboratory-based analytical procedures.

This approach uses a three-dimensional (3D) paper device using a wax printing fabrication technique and basic principles of origami to facilitate a very small test sample, a simple administration and a little time to use. To demonstrate the effectiveness of this device, assays were prepared to test human urine samples and to give an estimation of glucose and protein amounts in the samples. The major challenge of this technology is that paper is a porous material which makes

it to be difficult to precisely control the flow of fluids through μPADs. This can lead to inaccurate results or device failure [12].

2.1.5 Microwave microfluidic biosensor for monitoring blood glucose levels

The glucose sensor is a triple-ring microstrip patch integrated with a biomimetic microfluidic device capable of measuring a fixed volume of glucose solution in a sample [6]. A study performed by Xiaojun Yang et al., (2022) used this sensor to detect 50-500 mg/dL glucose solutions. The interaction of the glucose solution with the electromagnetic field on the patch's surface influenced both the resonance and the magnitude of reflection coefficient. The results indicated that the microfluidic device can reduce experimental error and enhanced the correlation between glucose concentration, resonant frequency, and reflection coefficient. The experiment on the sensor's stability verified the sensor's excellent stability and rapid response (~150ms). This biosensor can be optimized for both miniaturization and further sensitivity improvement [6].

2.1.6 Droplet based microfluidic devices

Droplet based microfluidics provide an isolated environment for performing a single reaction within a microscale-volume sample, allowing for a fast reaction with a high sensitivity, high throughput, and low risk of cross-contamination [13]. The process started by analytical chemists and engineers as a method of manipulating small volumes of liquid in an open environment. The small volumes needed make these approaches desirable for applications that use precious samples such as rare types or expensive reagents. Moreover, this technology offers versatility, which is important for point of care and at home sample analysis [14].The major challenge with this technology is droplet-based microfluidic devices are more complex, expensive to fabricate and not compatible with other devices.

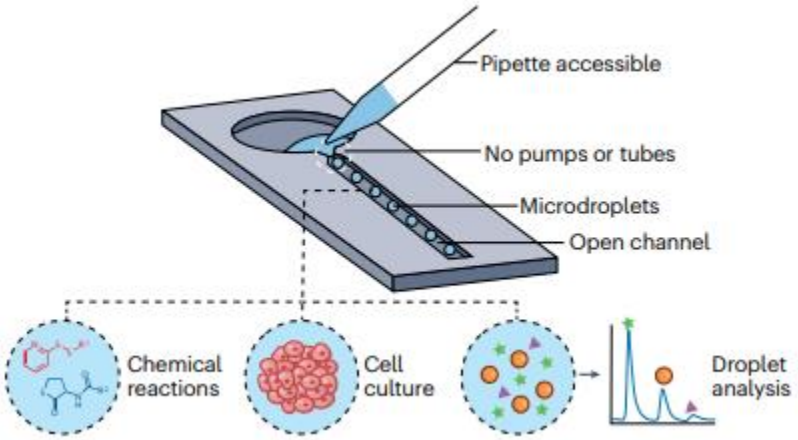

Figure 2. 2 Example of droplet based microfluidic device

2.1.7 Dipstick tests

Dipstick tests are used to test for a variety of substances in urine and blood, including glucose, ketones, pH, protein, and blood cells [15]. The dipstick test for glycosuria, which is caused by diabetes mellitus (DM), is widely used in clinical practice and public health screening owing to its advantages such as low cost, ease of use, and non-invasiveness. For the accurate determination of urine glucose, various detection methods have been employed based on techniques such as fluorescence, visible -near infrared spectroscopy, surface plasmon resonance and electrochemistry. Among these methods, there has been particularly high interest in the electrochemical sensing technique for urine glucose detection because of its advantages of low cost, fast response time, wide detection range, and ease of use. However, this method has limitations in terms of sensitivity, selectivity, reusability and quantitative evaluation of diseases [16].

Figure 2. 3 Dipstick tests

Table 2. 1 Summary of the types of microfluidic devices for diabetes detection

Types	Authors and Years	Advantages	Disadvantages
Microfluidic Paper based analytical devices (μPADs)	Nishat et al., (2021); Yetisen et al., (2013)	Simpler fabrication, lower cost, easier disposal, and the ability to operate without pumps or other supporting equipment	Paper is a porous material which makes it to be difficult to precisely control the flow of fluids through μPADs.
Biological Fluid-Based Glucose Sensors	Aggas et al., (2020)	Ease of production and collection	Low glucose concentrations in analytes such as saliva, tears and sweat, posing difficulties during correlation with blood glucose levels.
Smartphone-based electrochemical glucose monitoring system	Xu et al., (2022)	Rapid, and real-time point-of-care electrochemical glucose monitoring	Unclear and disputable correlation between glucose levels in blood and in some bio fluids which are secreted on body surface, low

			detection range and high sensitivity requirement.
Protein biomarker technique	Yang et al., (2022)	High sensitivity in detecting protein content	Non-portable instruments and unsuitable for rapid detection.
Dipstick tests	Hwang et al., (2022)	Low cost, ease of use, and non-invasiveness	Low sensitivity.
Microwave microfluidic biosensor for monitoring blood glucose levels	Zhang et al., (2022)	Excellent stability and rapid response (~150 ms)	Can be optimized for both miniaturization and further sensitivity improvement.
Droplet based microfluidic devices	Trinh et al., (2023)	Fast reaction with a high sensitivity, high throughput, and low risk of cross-contamination.	More complex, expensive to fabricate and not compatible with other devices.

By addressing the challenges and taking into account the recent technologies, it is more important to design a portable microfluidic device for detecting diabetes that is affordable, reliable and user friendly. This will have a significant impact on the diagnosis and early detection of diabetes.

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Research Process

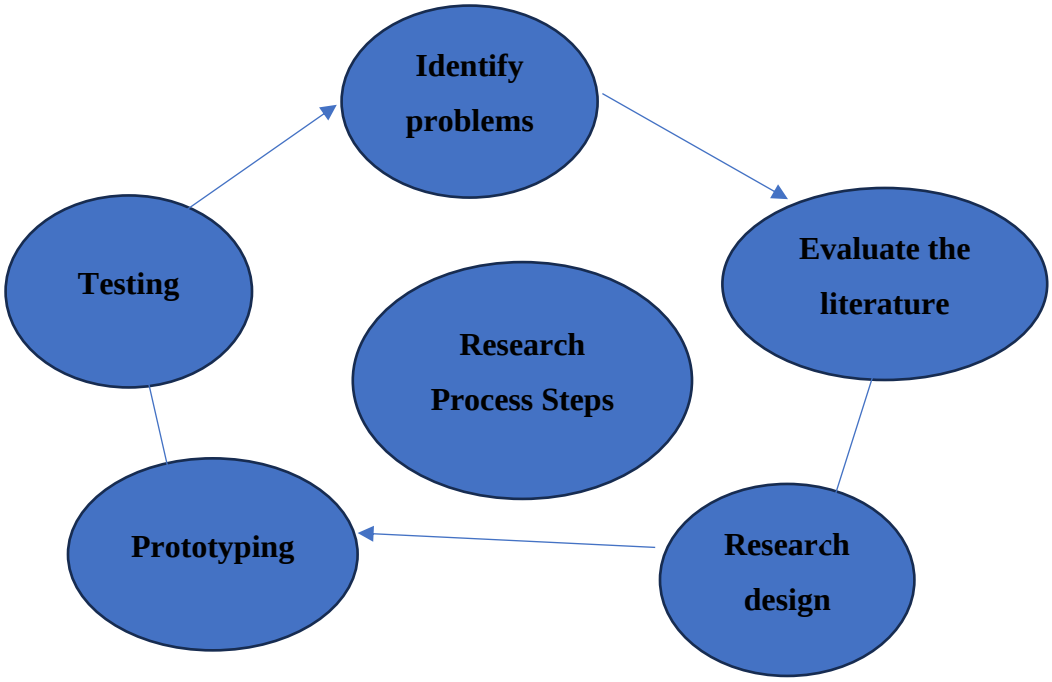

Figure 3. 1 Research process steps

3.2 Data collection

Data collection was conducted through semi structured interviews with participants aged between 15-70, by including both genders from different hospitals in Rwanda. The interviews were designed to explore participants' experiences, perspectives, and preferences regarding diabetes treatment, including healthcare access, and support services. Open-ended questions were employed to facilitate in-depth discussions and allow participants to articulate their experiences and viewpoints freely. Some questions were utilized to further explore participants' responses and obtain additional insights.

There are several questions we asked participants though our research and the answers they provided is the main part of the research that pushed us to develop this portable microfluidic device for diabetes

Q1. Is it very expensive for you to test early diabetes? Yes/no

Table 3. 1 Answers about cost of treatment from diabetic patients

Responses	**Frequency**	**Percentage**
Yes	18	90
No	2	10
Total	20	100

This table shows that 90 percent of 20 patients we asked have said that it is expensive for them to detect diabetes because its expensive

Q2. Is it easy for you to know the level of glucose in your blood? Yes/no

Table 3. 2 Answers about awareness of glucose level in blood or urine

Responses	**Frequency**	**Percentage**
Yes	0	0
No	20	100
Total	20	100

The table shows that 100 percent of 20 patients don't know the level of glucose in their blood or urine except if they visit hospital.

Q3. Can you know or detect early diabetes from home? Yes/no

Table 3. 3 Answers about having a portable treatment

Responses	**Frequency**	**Percentage**
Yes	1	95
No	19	5
Total	20	100

This table shows that 95 percent of 20 patients don't know or recognize early diabetes from home, this have pushed us to design and implement a portable device that can help them to know the level of glucose in their blood or urine

Q4. As individual, how do you perceive the importance of early detection of diabetes?

Answer:

Early detection empowers us by providing with timely information about health status, enabling us to take proactive steps towards managing condition of treatment options and reduce healthcare costs associated with managing diabetes-related complications.

3.3 Research Design Method

The Figure 3.2 is the block diagram of how components are connected and corresponding to each other where Raspberry pi pico is the micro controller we used to collect and analyse raw data from amperometric biosensor and the processed data displayed on OLED display as an output and if there is a problem or if a patient tests positive, buzzer will beep as output notification.The device also have GSM module that will help us to send results to a mobile phone device through SMS message. Builtin 3.7V lithium battery was used to keep the device running even when there is main electricity cut-off and for portability.

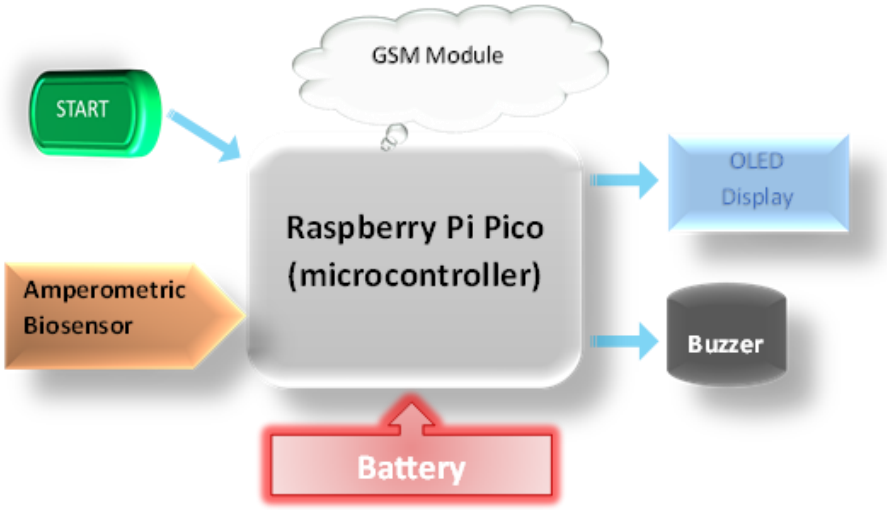

Figure 3. 2 Block diagram-A Portable Microfluidic Device for detecting diabetes.

Figure 3. 3 shows a flowchart of the device explaining the framework and how it works. The figure presented sample collecting from sensor to microcontroller and if the test for glucose levels yields a negative result, it indicates the absence of glucose in both the urine and blood samples. Conversely, a positive test result indicates the presence of glucose in both the urine and blood samples.

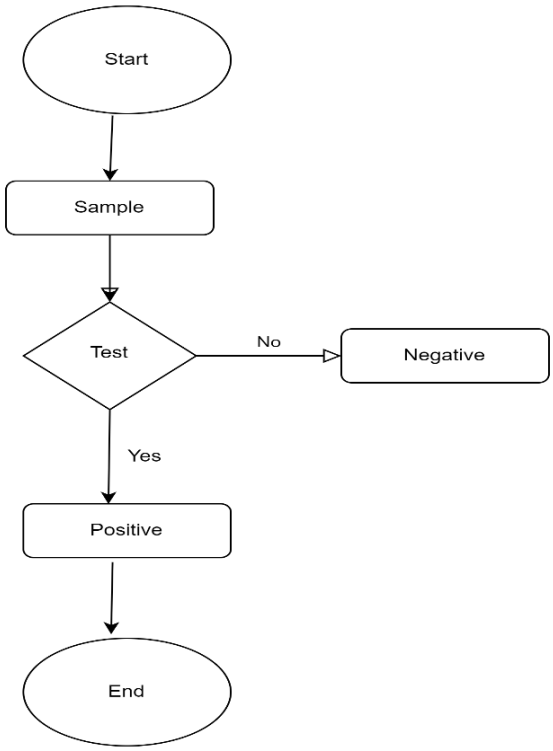

Figure 3. 3 Flowchart of a Portable Microfluidic Device for Detecting Diabetes

3.4 Hardware and software

3.4.1 Hardware components

3.4.1.1 Raspberry pi Pico

Raspberry Pi Pico(Figure 3.3) was used to control sensor, collect data from microfluidic chip and running code to automate processes and analysis [17]. Its key features include the following:

- RP2040 microcontroller chip designed by Raspberry Pi (Full address, UK)
- Dual-core Arm Cortex M0+ processor, flexible clock running up to 133 MHz
- 264kB of SRAM, and 2MB of on-board flash memory
- USB 1.1 with device and host support
- Low-power sleep and dormant modes
- Drag-and-drop programming using mass storage over USB
- 26 × multi-function GPIO pins
- 2 × SPI, 2 × I2C, 2 × UART, 3 × 12-bit ADC, 16 × controllable PWM channels
- Accurate clock and timer on-chip

- Temperature sensor
- Accelerated floating-point libraries on-chip
- 8 × Programmable I/O (PIO) state machines for custom peripheral support

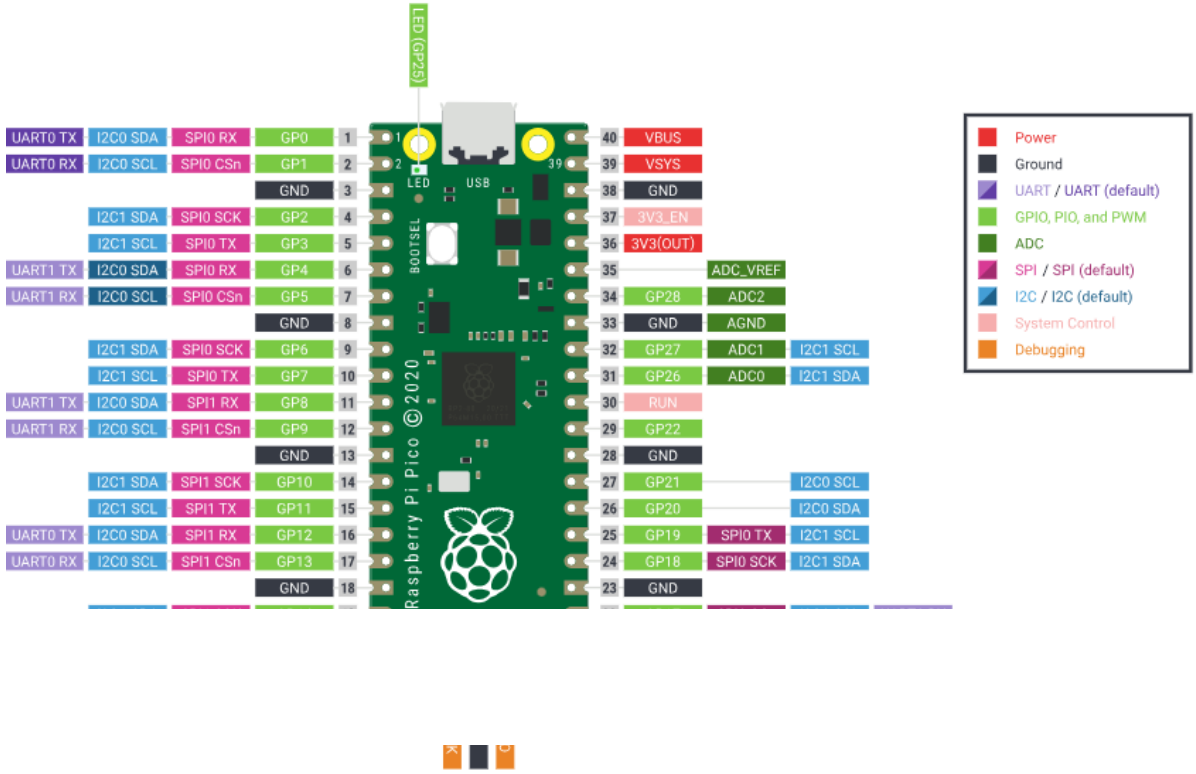

Figure 3. 4 Raspberry Pi Pico

3.4.1.2 Amperometric biosensor

Amperometric biosensor was used to detect glucose levels in blood and urine samples. In a microfluidic device, a small volume of the sample containing glucose can be passed over the biosensor, where an enzyme such as glucose oxidase catalyzes the oxidation of glucose, producing hydrogen peroxide as a byproduct. The biosensor the detects the current generated by the oxidation reaction, which is directly proportional to the glucose concentration in the sample. Glucose is quantified by the electrochemical measurement of hydrogen peroxide [18].

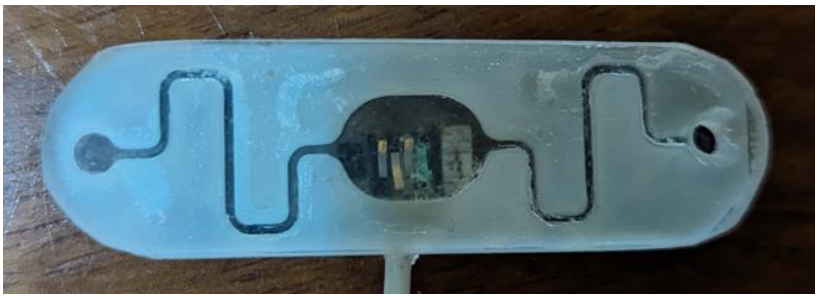

Figure 3. 5 Amperometric Biosensor

3.4.1.3 GSM SIM800L module

The SIM800L GSM/GPRS module is a miniature GSM modem that was used in this research to send SMS messages to the patients to alert them with the detected glucose levels. This module is able to do almost anything a normal cell phone can do, such as sending SMS messages, making phone calls, connecting to the Internet via GPRS, and much more [19]. At the heart of the module is a SIM800L GSM cellular chip from Simcom.

The operating voltage of the chip ranges from 3.4V to 4.4V, making it an ideal candidate for direct LiPo battery supply. This makes it an excellent choice for embedding in projects with limited space.

Figure 3. 6 GSM SIM800L Module

3.4.1.4 OLED display

The acronym “OLED” stands for Organic Light-Emitting Diode. In this research, OLED technology was employed to provide patients with visual display of their current glucose levels. By incorporating OLED displays into the microfluidic device, patients can conveniently and instantly view their readings in real-time. This visual feedback enhances patient engagement and enables prompt decision- making regarding diabetes management [20].

This 0.91” 128*32 Blue OLED Module offers 128*32-pixel resolution. They are featuring much less thickness than LCD Displays with good brightness and produce better and true colors. The Module is very compact and will add a great ever user interface experience to your project. They feature much less thickness than LCD displays with good brightness and also produce better and true colors. The connection of this display with the microcontroller is made through the I2C (also called as IIC) serial interface. The 0.91” 128*32 Blue OLED Display Module produces blue/white text on black background with very good contrast when supplied with 3.3V-5V Supply. The OLED Display Modules also offers a very wide viewing angle. The features of the display are as follows:

- SSD1306 compatible Driver IC
- Self illuminating display, no backlight needed
- Supports I2C interface
- Input Voltage: 3~5V
- Resolution: 128 x 32 with wide Visual Angle
- Working Temperature: -30°C~70°C
- Pin Definition: GND, VCC, SCL, SDA
- Pixel Color: Blue

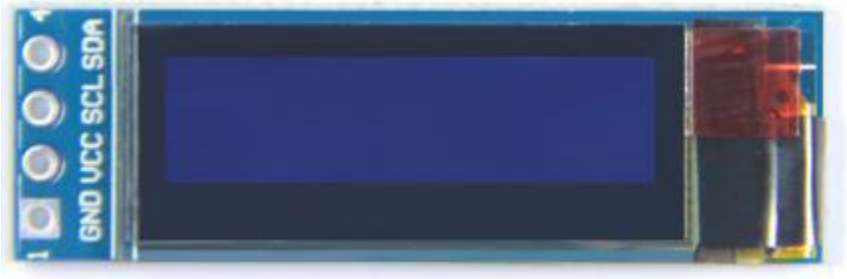

Figure 3. 7 OLED Display

3.4.1.5 Buzzer

Buzzer (Figure 3. 8) is an electronic component that generates sound through the transmission of electrical signals. Its primary function is to provide an audible alert or notification and typically operates within a voltage range of 5V to 12V. There are various types of these modules that differ in their sound generation mechanisms, operating principles, and applications [21].

Figure 3. 8 Buzzer

3.4.1.6 Battery

A lithium-ion or Li-ion battery (Figure 3. 9) is a type of rechargeable battery that uses the reversible intercalation of Li+ ions into electronically conducting solids to store energy.

Lithium-ion batteries power the lives of millions of people each day. From laptops and cell phones to hybrids and electric cars, this technology is growing in popularity due to its light weight, high energy density, and ability to recharge [22]. A single 3.7V lithium battery was used in the current study.

Figure 3. 9 3.7V Lithium battery

3.4.1.7 Jumper wires

Jumper wires (Figure 3.10) are simply wires that have connector pins at each end, allowing them to be used to connect two points to each other without soldering. Jumper wires are typically used with breadboards and other prototyping tools in order to make it easy to change a circuit as needed. Fairly simple. In fact, it doesn't get much more basic than jumper wires.

Figure 3. 10 Jumper wires

3.4.1.8 Momentary push button

A momentary push button or switch (Figure 3. 11) is a device that regulates whether an electric circuit is open or closed. They enable a circuit's current flow to be controlled (without the need to get in there and cut or connect the wires). Switches are essential components in every circuit

that calls for human input or operation [23]. There are countless switches available, including toggling, radial, DIP, momentary, drive, rocker, membrane, and the list goes on and on. Momentary switches require continuous compression. They will switch on when the user compresses the switch and will remain on only for as long as there is pressure on the switch. Once the pressure is removed, they will switch off. For example; a door buzzer or an electric drill. This momentary pushbutton will be used to switch between testing modes, whether it is urine test or blood test.

Figure 3. 11 Momentary push button

3.4.2 Software

3.4.2.1 Thonny (micro python)

Thonny (Figure 3. 12) is an Integrated Development Environment (IDE) for Python programming language. It is designed to be beginner-friendly, offering a simple and clean interface that is suitable for users who are new to programming as well as experienced developers [24]. Just like Microsoft Visual Studio or NetBeans IDE, Thonny makes it easier for programmers to code as it already comes with the essential tools, libraries, and dependencies that they need to get started. Thonny IDE provides a user-friendly environment for writing, debugging and experimenting with Python code, making it an excellent choice for beginners and educators alike.

Figure 3. 12 Thonny IDE

3.5 Summary

From several methods that relate with the research on portable microfluidic device and essential components that made up of the device designed in this study and data or samples collection as captured by amperometric biosensor and which were transmits those samples to the microcontroller to be processed. Thonny IDE environment which is a programming software that use python language to program raspberry pi as the main controller has also been presented.

CHAPTER 4. THE PROJECT RESULTS FROM IMPLEMENTATION

4.1 Results from implementation

The system uses amperometric sensor that is found in biosensors which holds the main part of this research study. The sensor uses artificial intelligence to collect blood or urine samples or raw data then send them to microcontroller (Raspberry Pi Pico) through universal asynchronous receiver/transmitter (UART) communication pins and those collected data were sent to microcontroller that will be executed using built-in model of data processing to give the output results, either over OLED display or over an online dashboard.

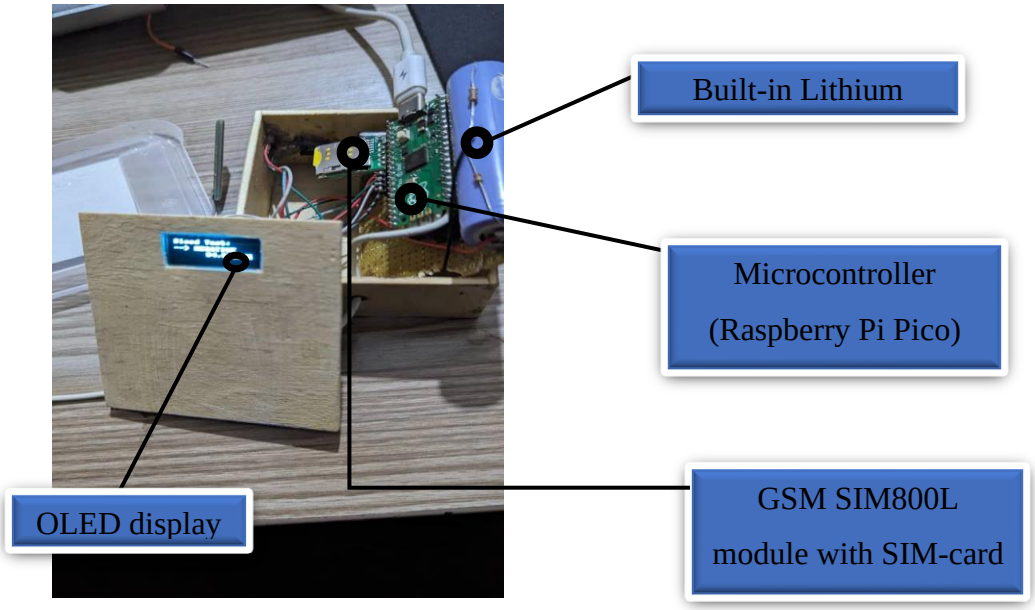

Figure 4. 1 Open implementation

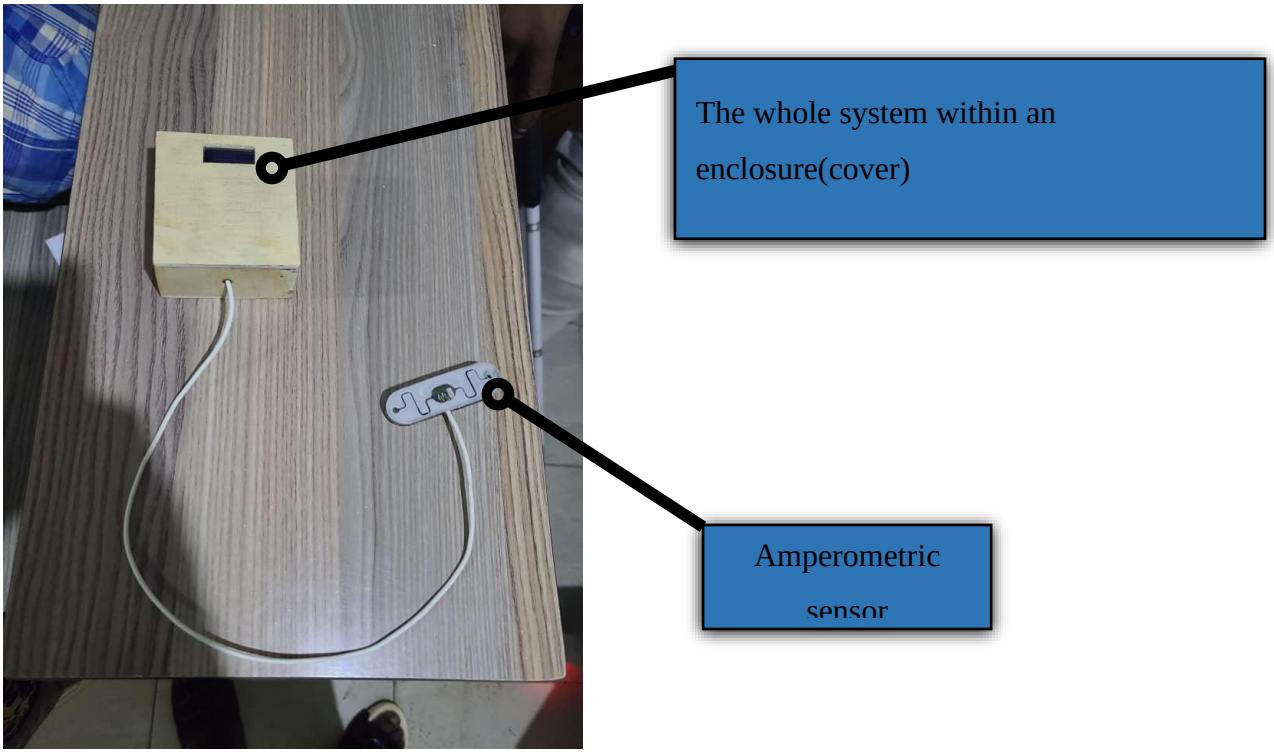

Figure 4. 2 Final implementation

4.2 Analyzing processed data

This device has a GSM module integrated, it uses SMS messages to notify a patient about thresholds of the processed samples so that he/she can know the results if he/she has diabetes and which level it has reached.

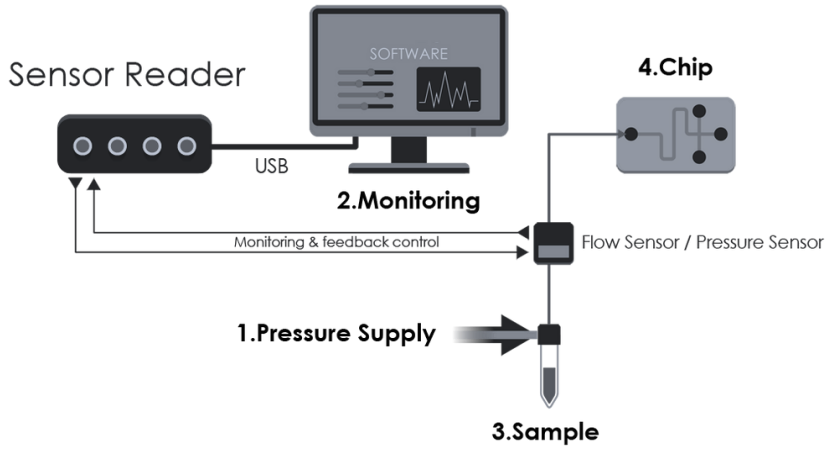

Figure 4. 3 How data is processed and visualized

4.2.1 Blood test for diabetes

When testing blood glucose, threshold values were utilized the system effectively classified test results as either positive or negative, facilitating timely communication of diagnostic outcomes to individuals. Tests yielding blood glucose levels falling within the range of 70mg/dL to 100mg/dL were consistently classified as negative for diabetes [25]. then the individuals received SMS notifications informing them of their negative test results. The notification message, “Blood test: patient is tested Negative” was delivered to the designated mobile phone number providing reassurance and clarity regarding their diabetes status.

Conversely, test results outside the designated range (less than 70mg/dl or greater than 100 mg/dl) were indicative of a positive diagnosis for diabetes. In such instances, individuals received SMS notifications conveying the positive result. The notification message, "Blood test: a patient is tested Positive".

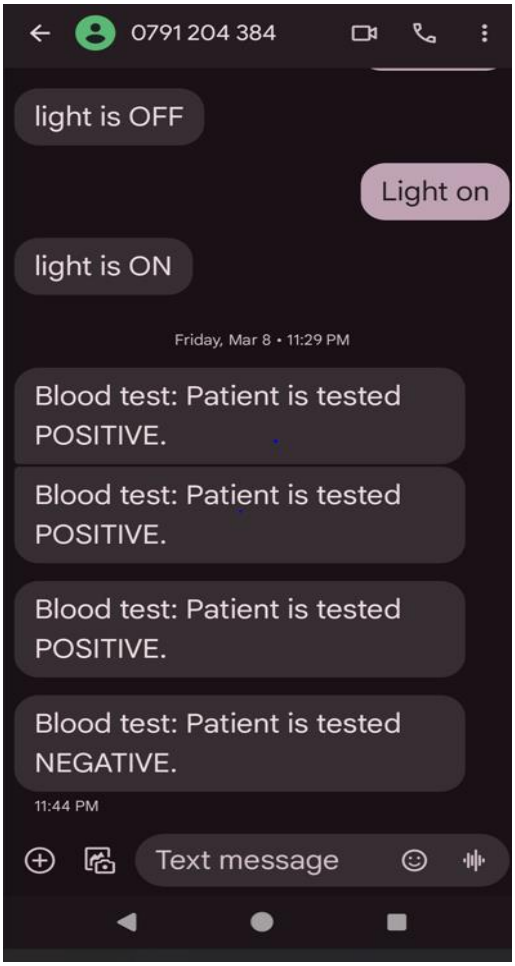

Figure 4. 4 Notification message

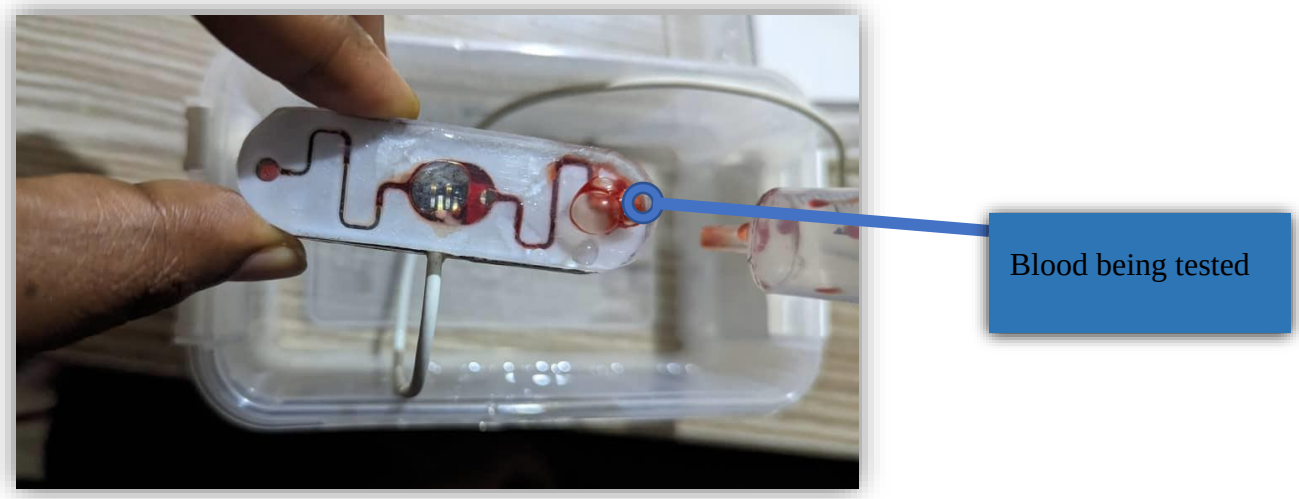

Figure 4. 5 Testing blood

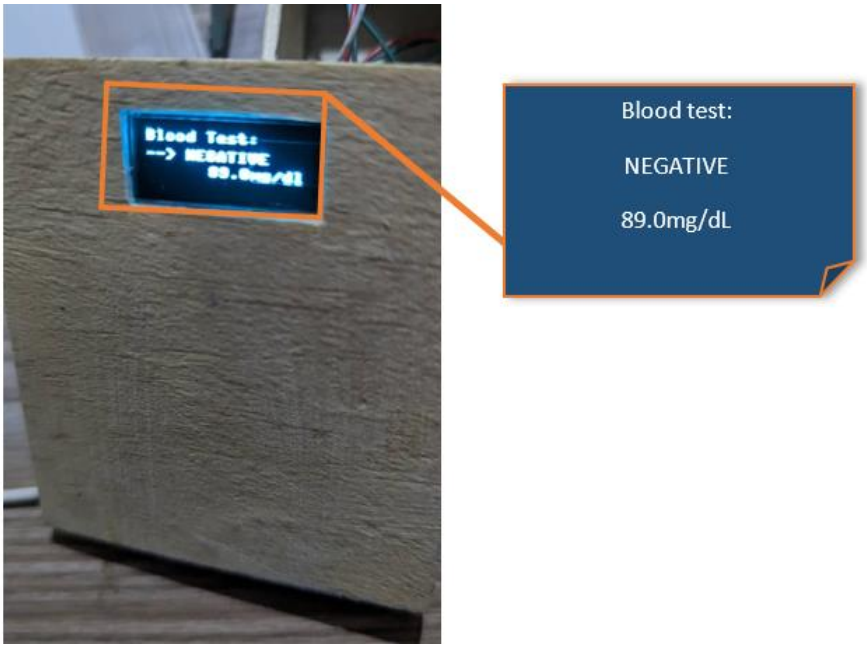

Figure 4. 6 Results of blood tested

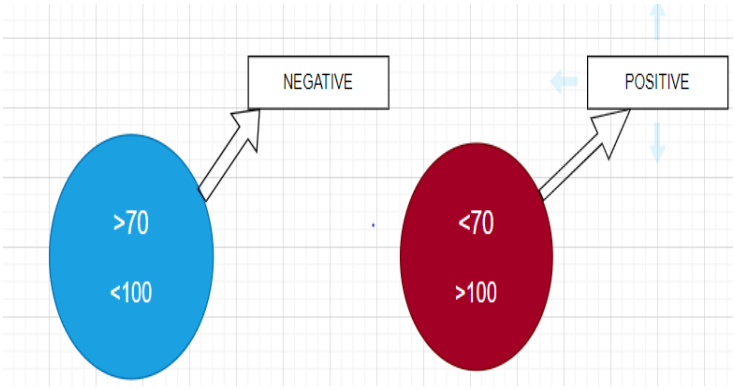

Figure 4. 7 Blood test thresholds for diabetes

4.2.2 Urine test for diabetes

The urine test for diabetes worked well, telling people if their test is positive or negative. If the result is between 1mg/dL and 15mg/dL, it is negative and they got a text saying urine test:"patient is tested Negative" If it is higher than 15mgdL, it is positive and they receive a text saying "Urine test: patient is tested Positive." This help people to know their diabetes status quickly and take action if needed.

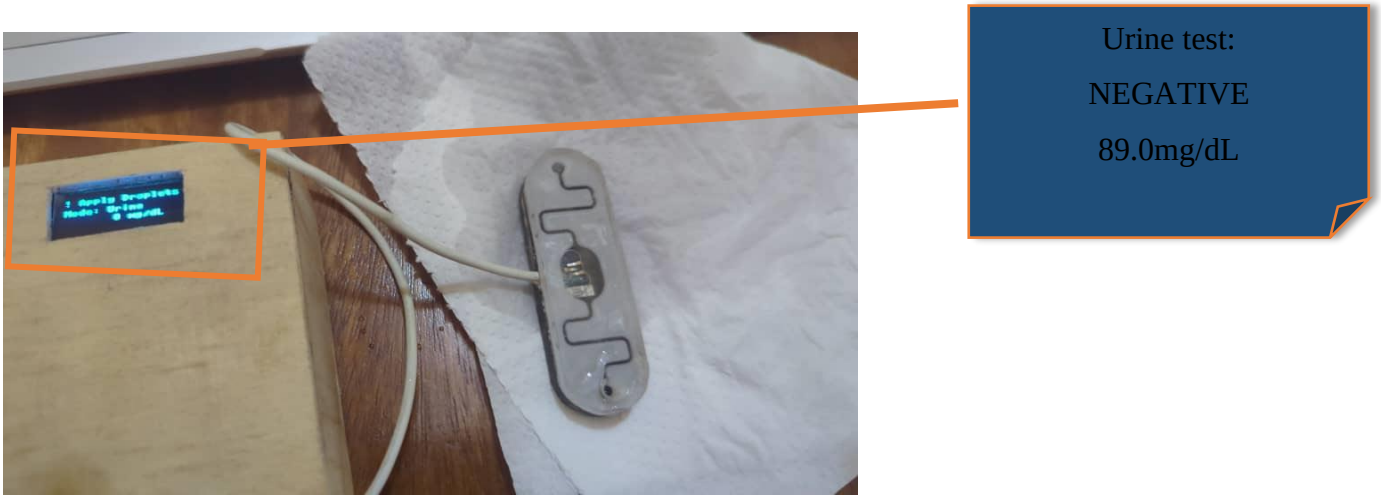

Figure 4. 8 Urine test

4.3 Summary

This chapter discussed about results and founding from developing portable microfluidic device. Results shows that during blood test for diabetes if threshold is in range of >100 and <70, a user is tested positive and if it ranges from <100 and >70 a user is tested negative

During urine test for diabetes if threshold is in range of above 15, a user is tested positive and if it is in range of 0 and 15, a user is tested negative.

CHAPTER 5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study presented the designing of a portable microfluidic device for detecting diabetes that is completely functional as it will demonstrate the feasibility of the design and allow for testing and evaluation. It is a small, user-friendly device, integrating sample processing and analysis modules, ensuring sensitivity and specificity in detecting urine and blood analytics by maximizing time and cost effectiveness, designing an easy-to-use user interface, and performing clinical validation are the main outcomes to achieve. In particular, in resource-constrained or distant healthcare settings, the successful conclusion of this research will result in a portable, ease of use with effective diagnostic instrument that can deliver quick and accurate results.

5.2 Recommendation

The development of this portable microfluidic device for diabetes detection represents a significant step towards point-of-care diabetes monitoring. However, further research is recommended to optimize the device's performance and functionality for real-world application.

To the research community, the current design focuses on glucose detection. Expanding the microfluidic chip's capabilities to detect additional biomarkers relevant to diabetes management, such as HbA1c, would provide a more comprehensive picture of a patient's diabetic health. Future research can explore integrating specific capture agents within the microfluidic channels to enable multi-analyte detection. The incorporation of data storage capabilities within the reader device, along with Bluetooth connectivity, would allow for data transfer or healthcare providers. This would facilitate telemedicine applications, enabling remote monitoring and improved patient care.

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APPENDICES

Appendix 1: Mode of Data Collection

Data collection is made by amperometric sensor and sends raw data or samples to microcontroller to process them and analyze them to give specific output.

We used momentary pushbutton to select/switch which test mode is being executed whether its Blood test or urine test.

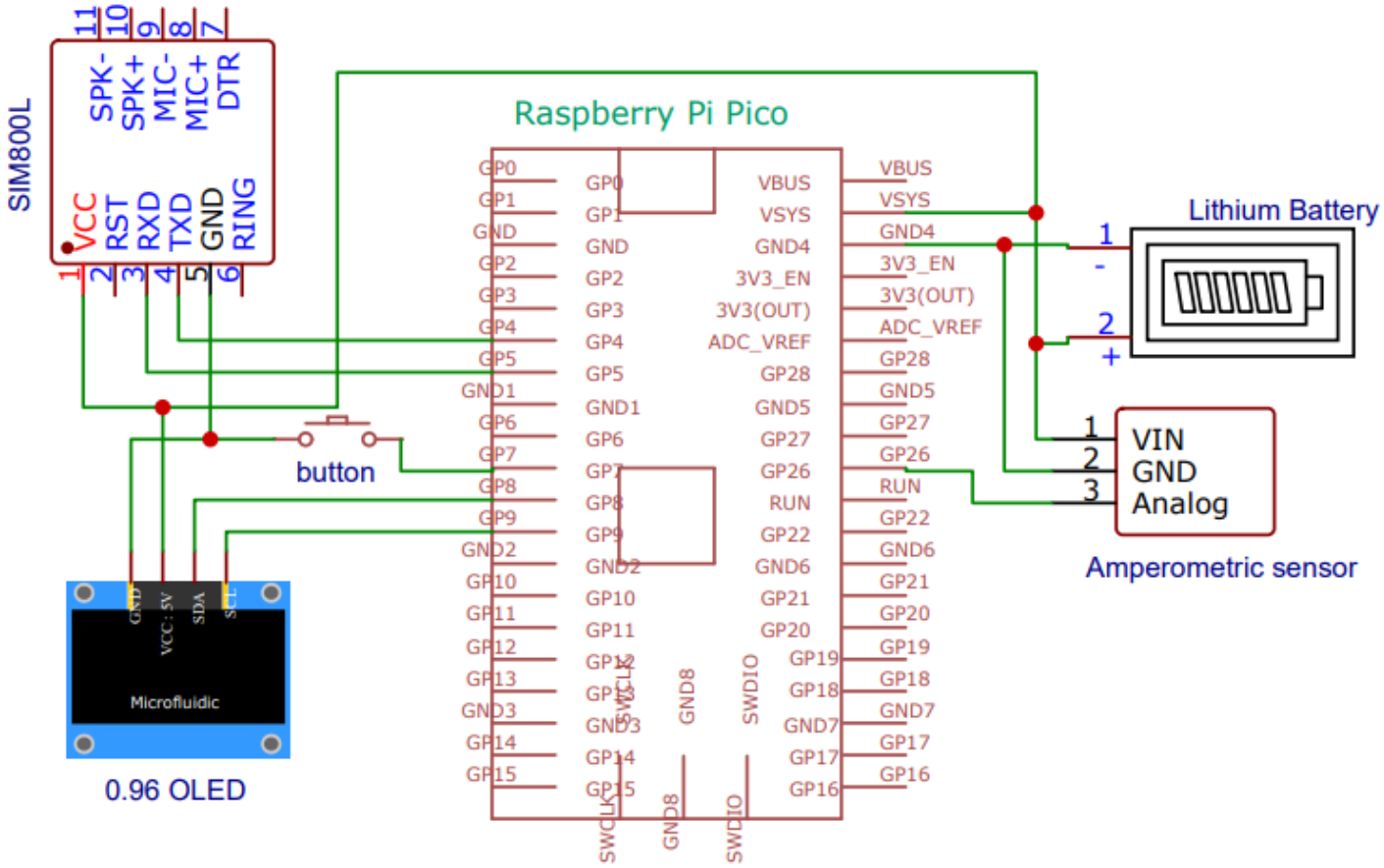

Figure I: *portable microfluidic device schematic diagram for detecting diabetes*

Appendix 2: The Utilized Codes

```
from machine import Pin, ADC, I2C, UART
import utime
from ssd1306 import SSD1306_I2C

# Initialize ADC
adc = ADC(Pin(26))  # Change Pin number based on your setup

# Initialize OLED display
i2c = I2C(0, scl=Pin(9), sda=Pin(8))
oled = SSD1306_I2C(128, 32, i2c)

# Define the GPIO pin connected to the button
button_pin = Pin(7, Pin.IN, Pin.PULL_UP)

# Initialize UART for GSM module
gsm_uart = UART(1, baudrate=9600, tx=Pin(4), rx=Pin(5))
destination_phone = '+250789619708'  # Specify destination phone number

# Function to send SMS
def send_sms(destination_phone, message):
    # Clear UART buffer
    while gsm_uart.any():
        gsm_uart.read()

    # Send AT command to set SMS text mode
    gsm_uart.write("AT+CMGF=1\r\n")
    utime.sleep_ms(100)
    gsm_uart.read()  # Clear response buffer

    # Send AT command to set SMS destination number
    gsm_uart.write('AT+CMGS="{}"\r\n'.format(destination_phone))
    utime.sleep_ms(100)
    gsm_uart.read()  # Clear response buffer

    # Send SMS message
    gsm_uart.write(message + "\x1A\r\n")
    utime.sleep_ms(100)

    # Return success message indicating SMS command was sent
    return "SMS command sent"

# Threshold for blood test
blood_threshold = 99
```

```
blood_threshold_Min = 70

# Threshold for urine test
urine_threshold = 15
urine_threshold_Min = 0

# Initial test method is blood
testing_blood = True

# Initialize flags to track whether an SMS has been sent for the current detection
blood_sms_sent = False
urine_sms_sent = False

# Initialize timestamps to track last SMS sent time
last_blood_sms_time = 0
last_urine_sms_time = 0

while True:
    # Read the ADC value
    adc_value = adc.read_u16()

    # Convert ADC value to percentage
    percentage = (adc_value / 65535) * 100

    # Clear OLED display
    oled.fill(0)

    # Toggle test method using button at pin 7
    if not button_pin.value():  # Button pressed
        testing_blood = not testing_blood
        utime.sleep_ms(100)  # Debounce button press

    # Edge detection for sending blood test SMS
    if percentage > blood_threshold and not blood_sms_sent:
        # Send SMS notification if positive
#         destination_phone = '+250781990307'  # Specify destination phone number
        message = 'Blood test: Patient is tested POSITIVE.'
        print(send_sms(destination_phone, message))  # Send SMS and print status
        blood_sms_sent = True
        last_blood_sms_time = utime.ticks_ms()  # Record the timestamp

    elif percentage < blood_threshold_Min and blood_sms_sent:
        # Wait for a delay before resetting flag
        if utime.ticks_diff(utime.ticks_ms(), last_blood_sms_time) >= 3000:  # 3000 ms delay
            blood_sms_sent = False  # Reset flag since no longer in positive range
```

```
    # Edge detection for sending urine test SMS
    if percentage > urine_threshold and not urine_sms_sent:
        # Send SMS notification if positive
#         destination_phone = '+250789619708'  # Specify destination phone number
        message = 'Urine test: Patient is tested POSITIVE.'
        print(send_sms(destination_phone, message))  # Send SMS and print status
        urine_sms_sent = True
        last_urine_sms_time = utime.ticks_ms()  # Record the timestamp

    elif percentage < urine_threshold_Min and urine_sms_sent:
        # Wait for a delay before resetting flag
        if utime.ticks_diff(utime.ticks_ms(), last_urine_sms_time) >= 3000:  # 3000 ms delay
            urine_sms_sent = False  # Reset flag since no longer in positive range

    if percentage > blood_threshold:
        oled.fill(0)
        oled.text('! Apply Droplets.', 0, 0)
        # Display current test mode on OLED display
        if testing_blood:
            test_mode = 'Blood'
        else:
            test_mode = 'Urine'
        oled.text('Mode: ' + test_mode, 0, 13)
        oled.text('0 mg/dL', 55, 24)
        oled.show()
    else:
        # Display test type on OLED display
        if testing_blood:
            oled.text('Blood Test:', 0, 0)
                # Check if percentage is within the threshold range
            if percentage <= blood_threshold and percentage >= blood_threshold_Min:
                oled.text('--> NEGATIVE', 0, 13)
                oled.text('{:.1f}mg/dL'.format(percentage), 50, 24)
                oled.show()

                # Send SMS notification if positive
#                 destination_phone = '+250781990307'  # Specify destination phone number
                message = 'Blood test: Patient is tested NEGATIVE.'
                print(send_sms(destination_phone, message))  # Send SMS and print status

            elif percentage < blood_threshold_Min+10 and percentage > blood_threshold_Min:
                oled.text('--> POSITIVE', 0, 13)
                oled.text('{:.1f}mg/dl'.format(percentage), 50, 24)
                oled.show()

                # Send SMS notification if negative
```

```
#               destination_phone = '+250781990307'  # Specify destination phone number
                message = 'Blood test: Patient is tested POSITIVE.'
                print(send_sms(destination_phone, message))  # Send SMS and print status
        else:
            oled.text('Urine Test:', 0, 0)
                # Check if percentage is within the threshold range
            if percentage <= urine_threshold and percentage >= urine_threshold_Min:
                oled.text('--> POSITIVE', 0, 13)
                oled.text('{:.1f}mg/dl'.format(percentage), 50, 24)
                oled.show()

                # Send SMS notification if positive
#               destination_phone = '+250781990307'  # Specify destination phone number
                message = 'Urine test: Patient is tested POSITIVE.'
                print(send_sms(destination_phone, message))  # Send SMS and print status

            elif percentage < urine_threshold_Min+10 and percentage > urine_threshold_Min:
                oled.text('--> NEGATIVE', 0, 13)
                oled.text('{:.1f}mg/dl'.format(percentage), 60, 24)
                oled.show()

                # Send SMS notification if negative
                destination_phone = '+250781990307'  # Specify destination phone number
                message = 'Urine test: Patient is tested NEGATIVE.'
                print(send_sms(destination_phone, message))  # Send SMS and print status

    # Wait for a short duration before next measurement
    utime.sleep_ms(500)
```