KHULNA UNIVERSITY OF ENGINEERING & TECHNOLOGY

Department of Biomedical Engineering

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Project Title:
Telechroma: A Smart Colorimetric Analyzer for Telemedicine Applications

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ABSTRACT

Over the years, telemedicine has grown in popularity which has enabled medical professionals to treat a wide variety of patients. In this era of telemedicine, where healthcare transcends geographical boundaries, the new device called Telechorma —basically, a smart colorimetric analyzer—stands out as a shining example of innovation and advancement. This device redefines the way we approach remote diagnostics and monitoring by seamlessly fusing hardware and software components into a flexible and easy-to-use solution. The primary purpose of this system is to use colorimetric analysis to determine the concentration of analytes. Telechroma includes a compact and portable hardware platform, along with a smartphone application making it accessible for both healthcare providers and patients. It incorporates colorimetric detection methods that rely on measurements of color changes in reaction solutions to determine analytes' concentration. The true innovation of this analyzer lies in its telemedicine focus. Utilizing Bluetooth technology, the measured values are securely and instantly transmitted to remote caregivers. This enables timely consultations and diagnoses, particularly valuable in remote areas where access to healthcare is limited. With the ability to provide affordable diagnostic testing, Telechroma may play a crucial role in enhancing healthcare accessibility and outcomes particularly for marginalized communities and individuals residing in remote areas.

DEDICATED TO

ALL THE MARTYRS IN PALESTINE

Chapter I

Introduction

1.1 Introduction to Telemedicine and Colorimetric Analyzer

The laws of patient care are changing as a result of the quick and revolutionary movement in the globe toward telemedicine brought about by the confluence of technology and healthcare. Telemedicine is the use of computers and automated data to deliver healthcare services to patients located far away from medical professionals. It is a solution for providing healthcare in remote areas [1,2]. Numerous services, such as consultations, diagnosis, and treatment, may be given using it. Since telemedicine may provide people access to healthcare treatments they would not otherwise have, it has grown in popularity in recent years.

Smart colorimetric analyzer (SCA) is a device that identifies different substances present in a solution based on color changes. They are reasonably easy-to-use and reasonably priced instruments. Colorimetric analysis is a well-established and precise method for quantifying the concentration of substances by observing changes in color. This technique is used in numerous fields, including chemistry, biochemistry, and, most notably, medical diagnostics. With a keen focus on assessing compounds found in bodily fluids, such as urine, this smart analyzer opens the doors to non-invasive, cost-effective, and rapid medical assessments.

The manner that healthcare is provided might be completely changed by the integration of telemedicine with colorimetric analyzers. Smart colorimetric analyzers can deliver quick and precise results for a range of tests, and telemedicine can let patients get medical treatment from the comfort of their own homes.

Smart colorimetric analyzers have a wide array of applications in telemedicine, ranging from diagnosing diseases like infections, cancer, and diabetes to monitoring chronic conditions like diabetes, heart disease, and kidney disease. Additionally, they are valuable tools for drug testing and ensuring food safety by detecting contaminants such as bacteria and toxins in food products. Using a portable hardware platform, the SCA easily connects to other telemedicine equipment including cellphones. It uses sophisticated colorimetric detection methods to measure a range of analytes. Through the telemedicine application, the findings are sent in real-time to healthcare practitioners.

Smart colorimetric analyzers have the potential to revolutionize the way that healthcare is delivered. By combining telemedicine with smart colorimetric analyzers, patients can receive rapid and accurate healthcare services from the comfort of their own homes.

1.2 Problem Definition and Motivation

It is imperative that the urgent issue of complicated diagnostic instruments and restricted access to healthcare, especially in impoverished and distant areas, be addressed. Timely illness identification and full healthcare services are hampered by the high cost and specialized knowledge of traditional diagnostic equipment. The project's primary motivation is to democratize healthcare by providing an integrated, affordable, and user-friendly solution for remote diagnostics. This will enable people from a wide range of socioeconomic and geographic backgrounds to have access to the desired medical instruments. It is a greater need now to improve illness diagnosis and global health equality by streamlining telemedicine technology and facilitating distant consultations. Some methods are necessary to build that will ultimately contribute to a more efficient healthcare system. In essence, projects need to be built that embody a commitment to democratize healthcare, offering a comprehensive, integrated solution that enhances healthcare accessibility, quality, and personal well-being.

1.3 Objective

The project mainly focuses in developing innovative colorimetric analysis tools, enable remote diagnostics, empower personal health monitoring, foster global health equity, and promote telemedicine as a standard of care. The main objectives are given below.

i. To develop a portable, affordable, and easy-to-use colorimetric analyzer.
ii. To develop a method for calibrating the analyzer to accurately measure the concentrations of target analytes in biological samples.
iii. To create a software platform for collecting, storing, and analyzing data from the analyzer.
iv. To demonstrate the feasibility of using the analyzer to diagnose diseases in remote areas.

Chapter II

Literature Review

2.1 Related Work

A smartphone-based colorimetric analyzer has been developed for telemedicine applications. The analyzer utilizes a pocket-sized colorimetric reader and commercially available urinalysis paper strips to quantify various parameters in urine samples. The reader includes a colorimetric multi-detection module and employs data reading methods using conversions of signal data to color maps or data models. It is battery-powered, inexpensive, lightweight, and capable of fast analysis. The system has been successfully applied to the detection of urinary glucose and protein, demonstrating reliable quantification. The analyzed data can be transferred to experts off-site, making it suitable for use by unskilled individuals on-site [3]. Additionally, a low-cost optomechanical device and an android application have been designed to capture substance samples and detect their concentration using colorimetric analysis. The device utilizes the saturation channel from the HSV color space and preliminary experiments have shown promising results [4]. In another study, a colorimetric analysis system has been developed that uses image sensors and can be used in applications like chemical, biological, and medical fields for data collection and analysis [5]. Furthermore, smartphone-based enzymatic biosensors utilizing colorimetric properties have been developed for the quantification of lactate and multiplexed analysis of various enzymes. The biosensors utilize a composite film and enzymes immobilized on the film to catalyze a reversible color change. A smartphone is used as a color detector, and the results have been confirmed by spectrophotometric measurements. The biosensors show promise for handheld analysis in various fields [6,7].

2.2 Background Study

Colorimetric analysis is a method of determining the concentration of a chemical element or chemical compound in a solution with the aid of a color reagent [8]. It is applicable to both organic compounds and inorganic compounds and may be used with or without an enzymatic stage. It is a widely used chemical technique that involves the measurement of the concentration or presence of a substance in a sample based on its color or the absorption or transmission of light by that substance [9]. This method relies on the principle that different substances can impart specific colors to a solution or exhibit varying degrees of absorption of light at specific wavelengths. The device or method that is used to perform colorimetric analysis is called colorimeter. A prepared solution absorbs a certain wavelength of light when monochromatic light passes through this light-sensitive gadget. It calculates how much light is absorbed and transmitted through the solution. The principle of colorimeter is based on the photometric technique that states when an incident light of intensity (lo) passes through a solution, then

- Part of the incident light is reflected (Ir)
- Part of the incident light is transmitted (Ii)
- Part of the incident light is absorbed (la)

Therefore,

Io = Ir + It + Ia

Here, the value of reflected light (Ir) is eliminated as lo and Ii values can calculate la. Values for the amount of light absorbed and transmitted are measured by keeping Ir constant. The principle of colorimetric analysis is based on Beer-Lambert's law [10].

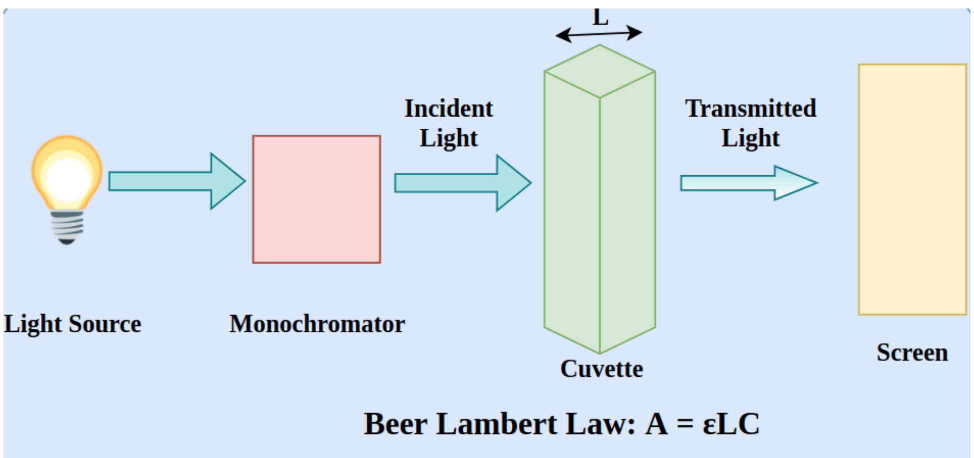


Figure 2.1 Illustration of Beer-Lambert law

Beer’s law:

The absorptive capacity of a dissolved substance is directly proportional to its concentration in a solution.

Lambert’s law:

The absorbance of light in a homogenous material/medium is directly proportional to the thickness of the material/medium.

Combined Beer-Lambert’s law:

The absorbance of a solution is directly proportional to the concentration of the absorbing material present in the solution and path length.

$$A = \varepsilon c l$$

where,

A=Absorbance

ε =Molar Absorptivity

c= Concentration

l=Length of the Path

Smart colorimetric analysis refers to colorimetric detection performed and assisted by any smart electronic component like smartphone, PC or Arduino based color sensors [11]. The color changes of an analyte can he assessed by an arduino-based color sensor and concentration change can be determined from the color change displayed on a smartphone-based app [12]. Colorimetric analysis can be performed for glucose analysis in urine by performing basic benedict’s test. Glucose measurement is crucial to determine diabetic status in any patient. Diabetes mellitus is a disorder in which blood sugar (glucose) levels are abnormally high because the body does not produce enough insulin to meet its needs. Benedict's reagent can test the presence of glucose in urine by visually observing changes in color of solution according to the concentration of glucose [13]. Benedict's reagent mixed with urine can display 3 different colors: brick red, green or yellow. Color manifestation indicates different level of diabetes and no color change indicates a healthy diabetes free individual.

2.3 Commercial Products

1. Colorimetric Water Analysis: CHEMetrics, Inc.

As water-based industries continue to expand, the need for water analysis grows with them. Colorimetry is the use of colored compounds to determine the concentration of a target chemical compound. It is the most reliable forms of water analysis and is used to test for a wide array of analytes. In colorimetric water analysis test kits, the target analyte causes the sample solution to change color to its concentration in the solution, and that change in color can be measured visually or instrumentally [14].

Figure 2.2 Colorimetric Water Analysis

2. ECD - Model CA6 - Copper Analyzer

The Model CA-6 Copper Analyzer is an on-line sequential sampling analyzer, a sequence of sampling, analysis and result processing is performed and repeated using colorimetric methods. The measurement is a colorimetric analysis using an LED light source and a heated colorimetric cell designed for measuring trace amounts of analyte in water [15].

Figure 2.3 ECD-Model CA6-Copper Analyzer

3. Stack Monitoring Kit

Yash Stack Monitoring Kit is the basic instrument used for the measurement of Particulate Matter (P.M) under iso-kinetic conditions and gaseous pollutants in flue gas emitted from the Stack/Chimney [16]. For P.M. measurement, known quantity is allowed to pass through glass fiber/cellulose thimble (Filter Media) at the predetermined iso-kinetic flow rate. Concentration can be determined by the gravimetric analysis. For Gaseous Pollutants, flue gas is allowed to pass through the suitable absorbing solution in impinger tube and concentration can be determined by the colorimetric analysis.

Figure 2.4 Stack Monitoring Kit

4. eXact Strip Cyanide for Water Quality Testing (484003)

Designed for monitoring effluents and surface waters, the eXact® Strip Cyanide Kit requires as little as two minutes for cyanide colorimetric analysis [17]. Color reading can also be made using a colorimeter or spectrophotometer for more precise determination. Detection sensitivity is 0.01 ppm (mg/L), with a range to 1.0 ppm (mg/L). The eXact® Strip Cyanide Kit is the quick and accurate solution for testing cyanide concentrations.

Figure 2.5 eXact Strip Cyanide for Water Quality Testing

Chapter III

Methodology and Strategy

3.1 Technical Specification

To build the project successfully, the hardware and software components were the most important prerequisites. The description of these components is given below.

3.1.1 Hardware Description

To make this project as cost effective as possible, we sought to construct it with fewest components. Below are descriptions of each of the mentioned products.

Arduino Nano (V3.0) [18]

Developed by Arduino.cc and first published in 2008, the Arduino Nano is an open-source microcontroller board that can be used with a breadboard. It is based on the Microchip ATmega328P microcontroller (MCU). It has a smaller physical size but provides the same specifications and connections as the Arduino Uno board. The Arduino Nano has thirty male I/O headers in a layout similar to a DIP-30. These headers may be programmed using the online and offline Arduino Software integrated development environment (IDE), which is available for all Arduino boards. The board may be powered by a 9 V battery or a type-B mini-USB connection.

Figure 3.1 Arduino nano

TCS230/TCS3200 Color Sensor Recognition Module [19]

TCS3200 is the colorama-to-frequency programmable converter launched by TAOS company. As the first RGB color sensor in the industry, it has the single CMOS circuit integrated with configurable silicon photodiode and current frequency converter. It integrates three kinds of RGB light filters into the single chip. TCS3200 can be connected with microprocessor or logic circuit since it can drive standard TTL or CMOS logical input. The sensor outputs digital signal without the need of A/D conversion, so the circuit becomes simpler and can process more than 10 bits signal in each color channel.

Figure 3.2 TCS3200 Color Sensor Recognition Module

Arduino Bluetooth Module (HC-05) [20]

A Bluetooth module called HC-05 is intended for wireless communication. It is possible to use this module as a slave or master configuration. Numerous consumer applications, including wireless headsets, game controllers, mice, keyboards, and many more, make use of it. Depending on the transmitter and receiver, environment, geographic location, and urban settings, its range can reach less than 100 meters. The established IEEE 802.15.1 protocol is what allows one to create a wireless Personal Area Network (PAN). It transmits data over the air using frequency-hopping spread spectrum (FHSS) radio technology.

Figure 3.3 Bluetooth Module (HC-05)

Breadboard [21]

A breadboard is a type of electronics prototyping board that is used to build and test electronic circuits. It is called a "breadboard" because it is designed to look like the slotted board that was once used to hold bread.

A breadboard shown in figure 3.4 consists of a plastic base with multiple rows of holes arranged in a grid pattern. These holes are used to insert the leads of electronic components such as resistors, capacitors, transistors, and integrated circuits. The breadboard has metal clips beneath the holes that make contact with the component leads and hold them securely in place. Breadboards are a convenient way to build and test electronic circuits because they do not require soldering, which makes it easy to change or modify the circuit. This makes them an ideal tool for prototyping, experimentation, and learning about electronics. Breadboards come in different sizes and shapes, but the most common type is the full-size breadboard, which has a rectangular shape and can accommodate a large number of components. There are also mini breadboards, which are smaller in size and can be used for building compact circuits or for use in portable devices.

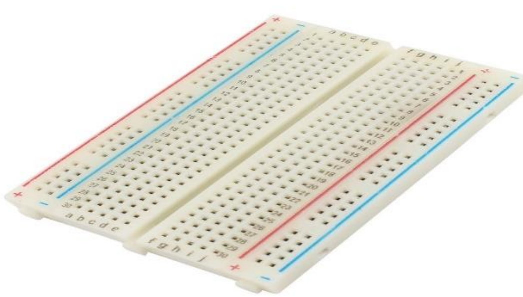


Figure 3.4 Breadboard

Connecting Wire [22]

Connecting wires, also known as jumper wires, are wires that are used to connect electronic components on a breadboard or other prototyping board. They are typically made of stranded or solid core insulated copper wire and come in different lengths, colors and gauges. They can have different connectors at the ends, such as male or female headers, alligator clips, or even bare wire. The most common type of connecting wire shown in figure 3.5 is the male-to-male jumper wire, which has a male connector on each end. These wires can be plugged directly into the breadboard holes and are typically used to make connections between the power supply and other components. Connecting wires are an essential tool for building and testing electronic circuits. They make it easy to connect components and make changes to a circuit without having to solder or unsolder connections.

Figure 3.5 Connecting wire

3.1.2 Software Description

Arduino IDE [23]

Arduino IDE (Integrated Development Environment) is a software application that allows users to write, upload, and debug code for microcontroller boards based on the Arduino platform. It provides an easy-to-use interface for coding, compiling, and uploading sketches (programs) to an Arduino board. The IDE supports a variety of programming languages, including C and C++, and includes a library of pre-written code snippets and functions to help users get started quickly. The Arduino IDE is free and open-source software, and is available for Windows, Mac, and Linux operating systems. A simple sketch is shown in figure 3.6.

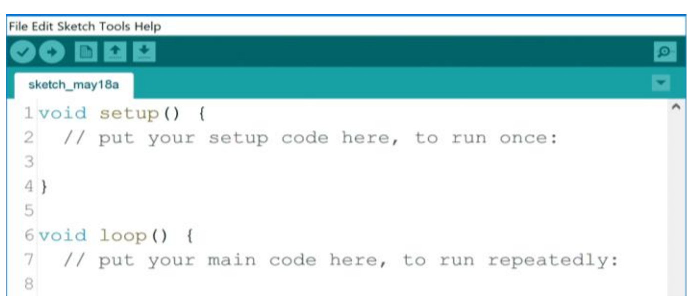


Figure 3.6 Arduino IDE

MIT App Inventor [24]

A high-level block-based visual programming language called MIT App Inventor (also known as MIT AI2) was created by Google at first and is currently maintained by the Massachusetts Institute of Technology. It enables novices to develop computer programs for the two operating systems—iOS and Android—which are currently in beta testing as of September 25, 2023. It is free and open-source and is distributed under two licenses: an Apache License 2.0 for the source code and a Creative Commons Attribution ShareAlike 3.0 Unported license. Users may design applications that can be tested on Android and iOS devices and built to operate as Android apps using the web interface, which has a graphical user interface (GUI) that is very similar to Scratch and StarLogo. It makes use of the MIT AI2 Companion smartphone app, which offers live testing and debugging.

Figure 3.7 Logo of MIT App inventor

SolidWorks 2022 [25]

Dassault Systèmes produces and distributes solid modeling computer-aided design, computer-aided engineering, 3D CAD design and collaboration, analysis, and product data management software under the SolidWorks (stylized as SOLIDWORKS) brand. SolidWorks software was being used by almost 7 million engineers and designers by 2023 to produce sophisticated 3D models and production-ready 2D and 3D engineering drawings using a parametric feature-based methodology. Users using SolidWorks may also carry out simulations and analysis, such as Finite Element Analysis. The product emphasizes improved collaboration, better design tools, and quicker modeling.

Figure 3.8 Logo of SolidWorks

3.2 Proposed Circuit Diagram

The proposed circuit diagram was drawn in Fritzing software. It is shown in figure 3.9.

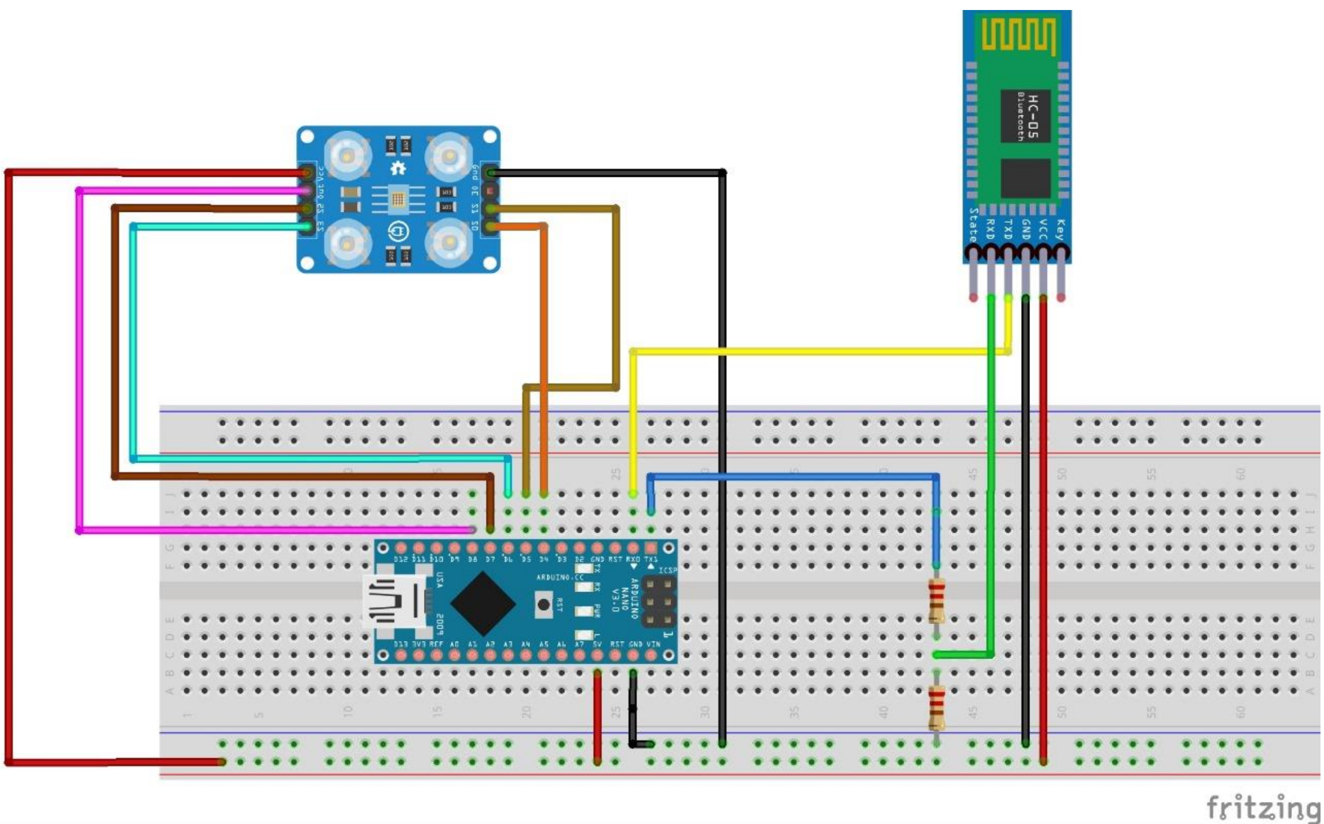


Figure 3.9 Proposed circuit diagram

3.3 Proposed 3D model

The development of the device involved a meticulous design process. The base and cover of the apparatus were designed using the sophisticated interface of SolidWorks 2022. Careful consideration was given to the dimensions, ensuring precision and functionality. Figure 3.10 shows the 3D model for the base of the device. The dimensions (in inches) were taken from the length, width and height of the circuit. The extrusion was made to have a perfect height for the Bluetooth module without creating any contact. Moreover, there was an extrude cut made for the switch in the body of the base.

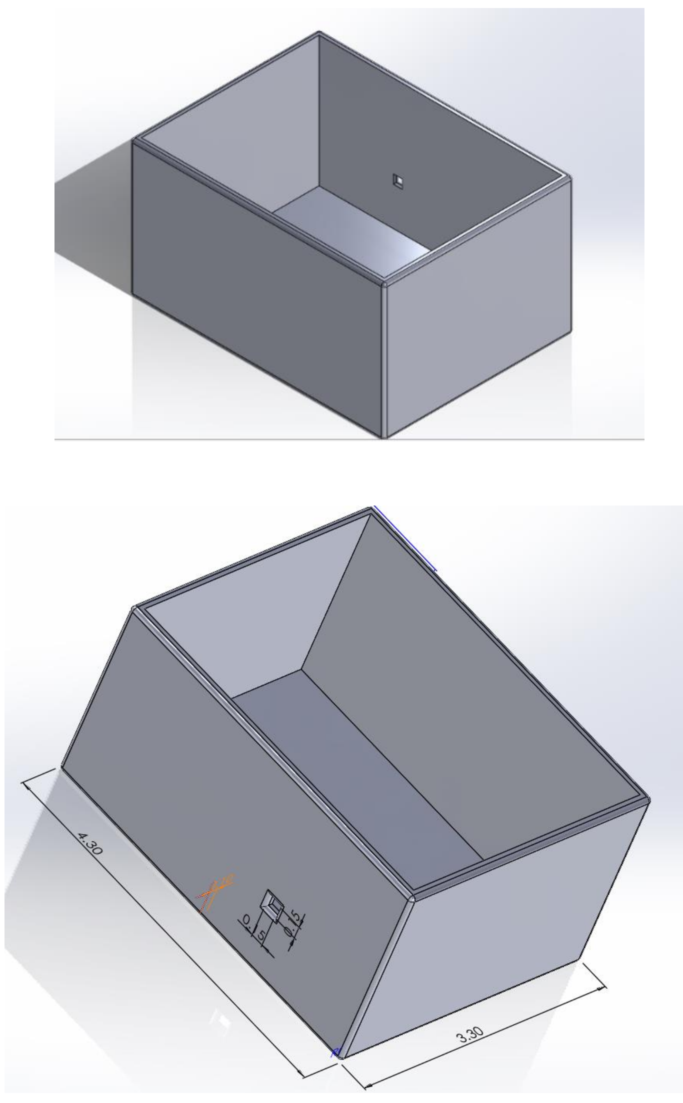
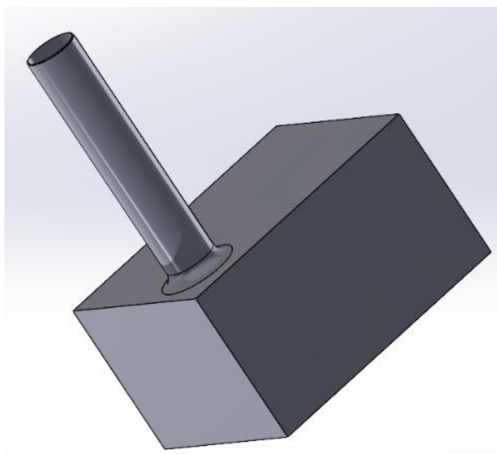
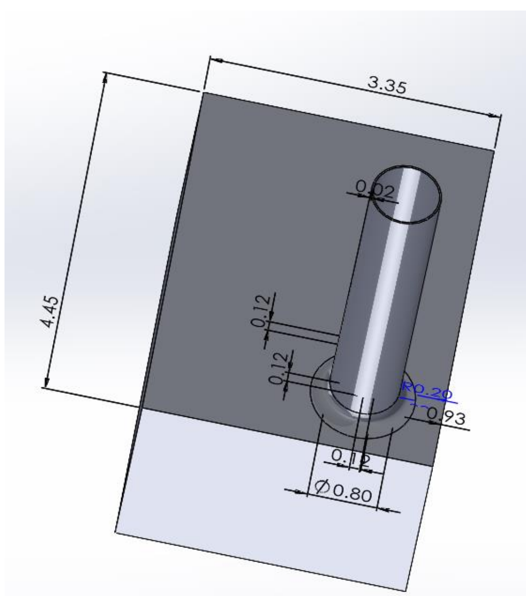


Figure 3.10 Proposed model for base with its dimension

Figure 3.11 shows the proposed design for the cover of the device. The cover design was given dimension (in inches) by measuring the height and length the test tube would be kept on during the experiments. This system not only facilitated the collection of biological samples but also ensured their integration into the analysis process, emphasizing the user-centric approach of this innovative medical device. A different plane was taken on the test tube handling system to add a block for the test tube to be sill in position with respect to the color sensor. More designing was performed to make a platform for the test tube holding system. Moreover, the edges were kept smooth for the user-friendly interface. The cover was kept a little bit loose to be fit with the base after full assembly of the two parts.





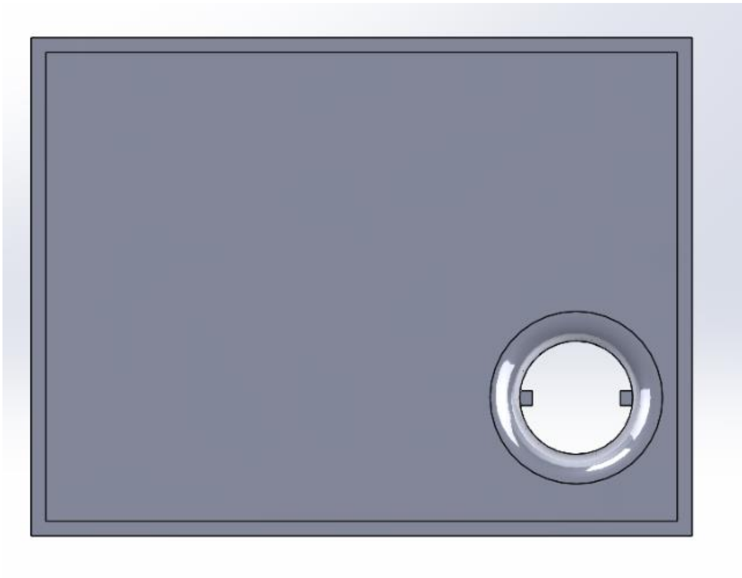


Figure 3.11 Different views of the proposed model for cover with its dimension

3.4 Proposed Flow Diagram

The proposed flow diagrams are shown in figure 3.12. and figure 3.13.

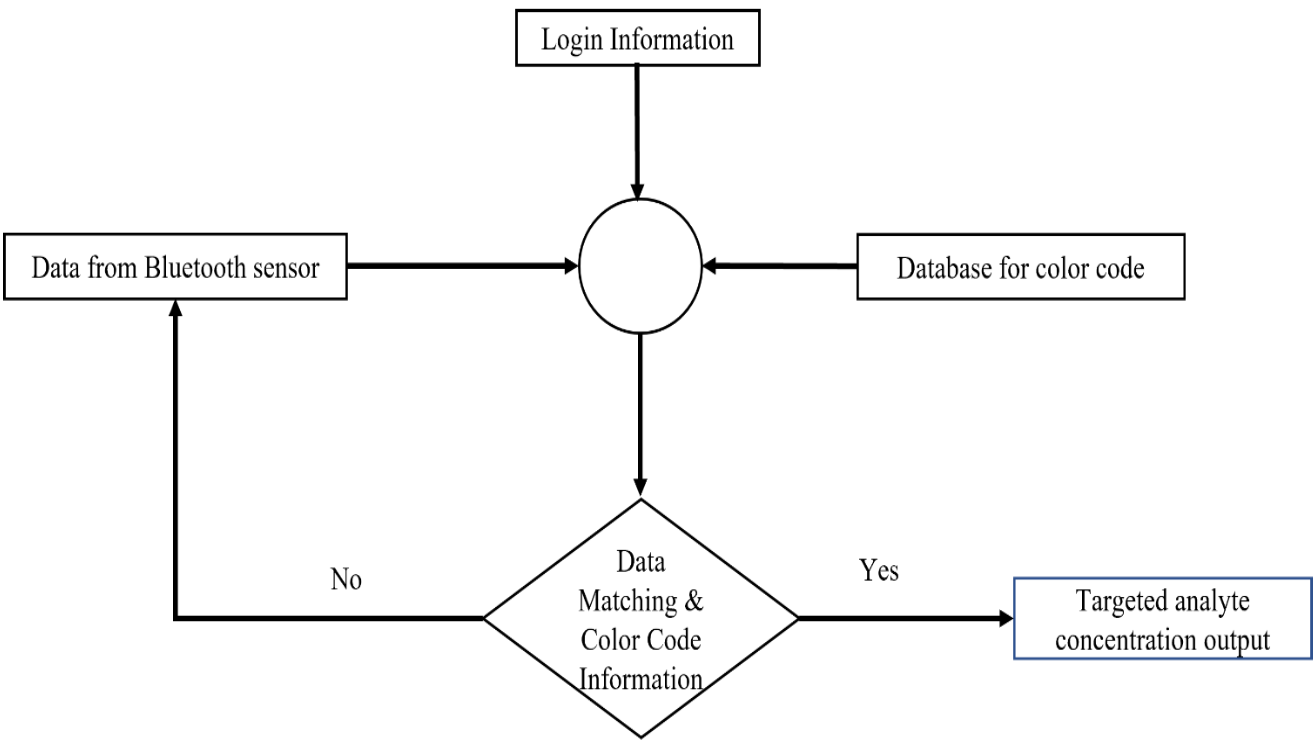


Figure 3.12 Proposed flow diagram (using device)

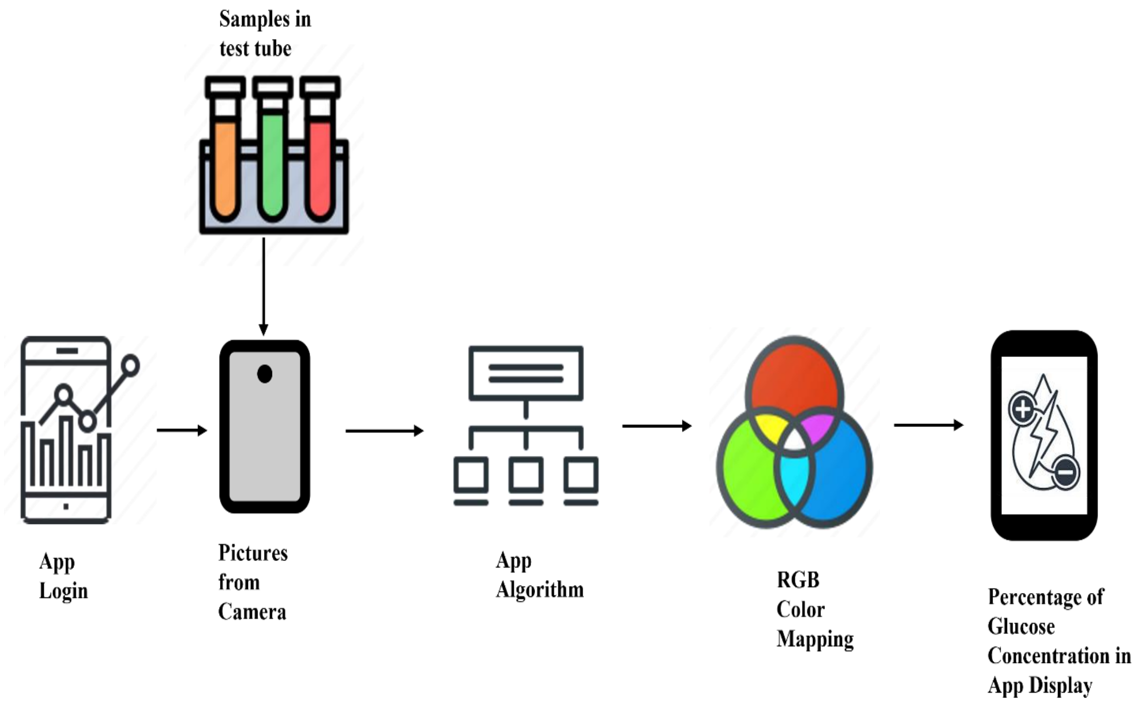
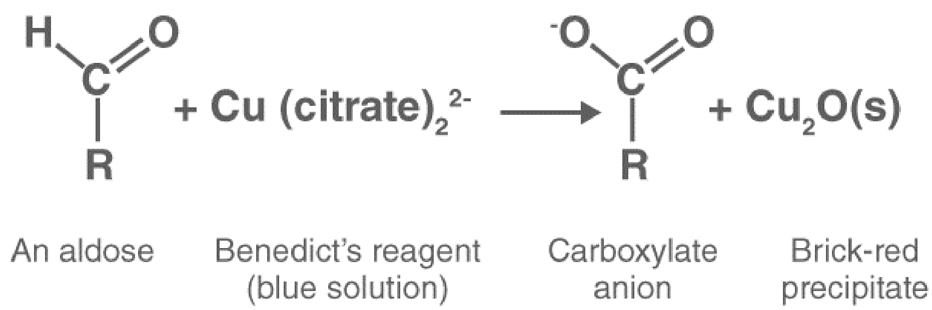


Figure 3.13 Proposed flow diagram for the alternative application (using camera)

3.5 Working Procedure

Telechroma presents an innovative and sophisticated approach to revolutionize healthcare diagnostics and monitoring, especially in the context of telemedicine. The project is primarily centered around the development of a colorimetric analysis system that can detect even subtle color changes in biological analytes, with a specific focus on urine due to its diagnostic significance.

The working procedure of this system was initiated with the collection of a biological sample, in this case, urine. The tests were performed in Biochemistry and Physiology Laboratory (Room No.: 503, Fourth floor, Block C) of department of biomedical engineering in KUET. Tests were done utilizing urine samples from a diabetic patient and a healthy subject to compare the color changes when Benedict's reagent is applied. Benedict's solution, a deep-blue alkaline reagent, was used, containing copper sulfate pentahydrate ($CuSO_4 . 5H_2O$), sodium carbonate (Na_2CO_3), sodium citrate ($Na_3C_6H_5O_7$), and distilled water. This solution was critical in the analysis as it provided the necessary alkaline conditions for the redox reaction and acted as a complexing agent to prevent the degradation of copper (II) ions into copper (I) ions during storage. The Benedict's test involved heating the solution containing reducing sugar with Benedict's reagent. Under alkaline conditions, the reducing sugar was converted into a strong reducing agent called enediols. During the reaction, enediols reduced the cupric ions (Cu^{2+}) in Benedict's reagent, resulting in the formation of insoluble red copper oxide (Cu_2O), visible as a red precipitate. In cases where the concentration of reducing sugar was high, the color became more intense, ranging from yellow to orange, then to red (light red), and finally to brick red (dark red). This color change was easily detected and quantified. The reaction is given below.



This sample was subjected to colorimetric analysis using a color sensor. The sensor's ability to precisely measure color changes in the sample was instrumental in assessing variations in analyte concentration. The novelty of this project extended to its seamless integration of hardware and software components, ensuring the accuracy and user-friendliness of the system. Once the colorimetric analysis was complete, the data was wirelessly transmitted to a designated smartphone app via a Bluetooth module. The smartphone app was designed in the MIT app inventor interface to provide a user-friendly interface for both patients and healthcare professionals, where the analyzed data was displayed in real-time.

In an alternative procedure, a mobile camera was used to capture the picture of the solution, and the pixel values were compared to detect the color of the solution, which provided the concentration of glucose. This approach offered flexibility and convenience for users in cases where a dedicated color sensor may not be available or necessary. This approach, alongside the color mapping based on observed color changes, provided a valuable tool for detecting diabetes and assessing glucose concentration in urine, making it a promising tool in the realm of telemedicine.

Chapter IV

Implementation

4.1 Circuit Implementation

Figure 4.1 shows the implemented circuit.

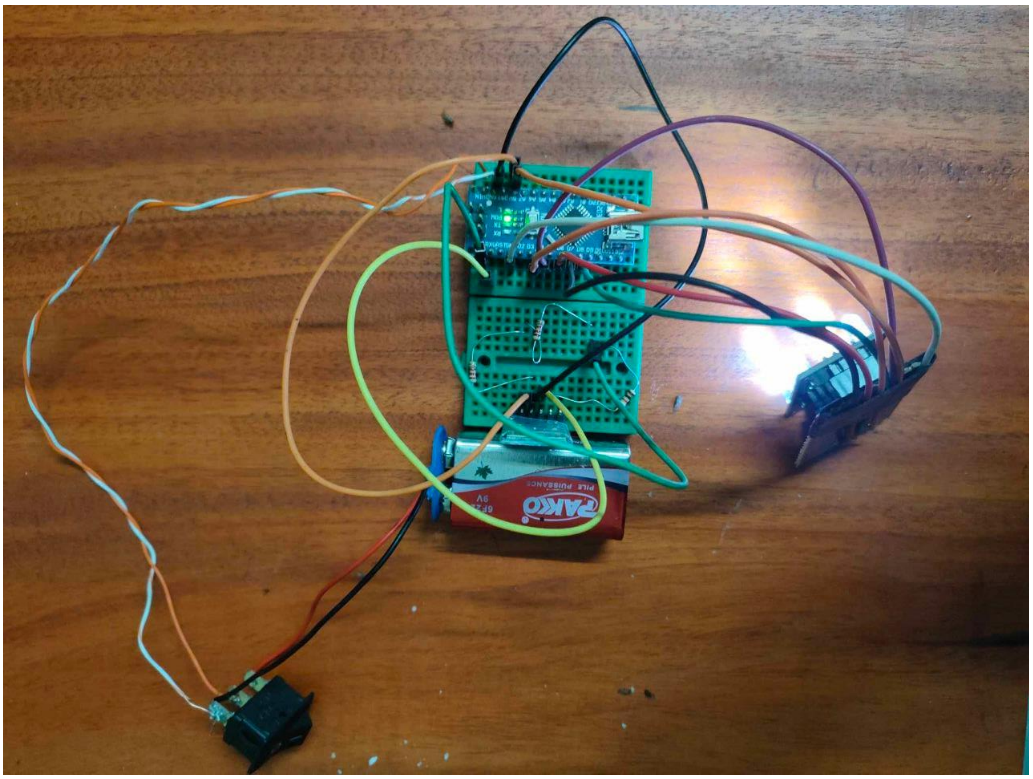


Figure 4.1 The implemented circuit

4.2 3D Model Implementation

The 3D models were printed in the Fabrication Laboratory (Fab Lab) of KUET. First of all, an application was written to the coordinator of Fab Lab requesting for the permission to use the 3D printer for the laboratory project. After receiving the confirmation email of having the permission granted, the two .stl files were sent via email with a message received of the estimated time to complete the fabrication of about 9 hours for two models running parallelly in two different printers namely Ultimaker and Prusai3. Polylactic acid (PLA) was used as the default filament.

Figure 4.2 and 4.3 show the images of the printed models of base and cover respectively. Figure 4.4 shows the assembled view of the base and cover parts.

Figure 4.2 The printed base

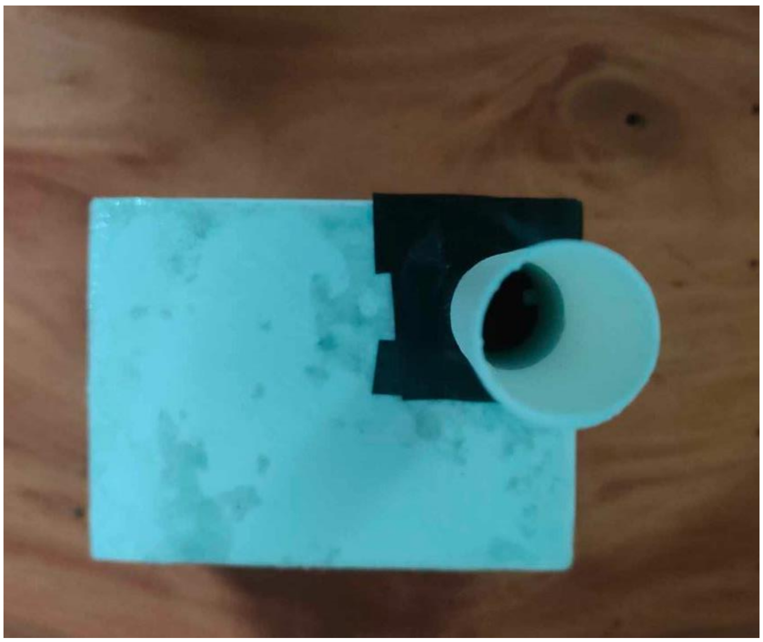


Figure 4.3 The printed cover

Figure 4.4 The assembled base and cover

4.3 Implemented Workflow

The operational process of the system commenced with the collection of a biological sample, specifically urine. Urine samples from both a diabetic patient and a healthy subject were employed for comparative color analysis upon the application of Benedict's reagent. This analysis entailed extracting 2 ml (equivalent to 10 drops) of Benedict's reagent, followed by its placement into a clean test tube. Subsequently, approximately 1 ml of the urine sample was introduced into the Benedict's reagent. The test tube was then subjected to direct heating over an open flame for a duration of 3-5 minutes, during which the observers noted the alteration in the color of the solution and the formation of any precipitate.

Within the system, the color sensor was employed to identify the color of the solution by assessing its three fundamental color components: red, green, and blue. In the context of the urine glucose test involving Benedict's reagent, fluctuations in glucose concentration within the urine sample led to discernible alterations in the solution's color. When glucose levels were low, the solution exhibited a green hue. As the glucose concentration increased in diabetic patients, the solution's color transitioned from yellow to orange, then to red (light red), culminating in brick red (dark red). This marked color transformation was promptly detected by the system's color sensor, enabling the eventual determination of glucose concentration.

(a)

(b)

(c)

Figure 4.5 Benedict’s test, (a) The sample. (b) Heating with Benedict’s solution and (c) The changed color sample

Figure 4.6 The color samples for application testing

The recorded color data was then transmitted to a smartphone application through a Bluetooth module. Subsequently, this data was cross-referenced with a predefined color map stored in the application's database. The color mapping, previously established by analyzing solutions of varying colors, was integrated into the software. Upon a successful data match with the color code information, the application furnished both patients and physicians with the glucose concentration within the urine sample, aiding in the detection of diabetes. The color mapping scheme provided a tangible means of gauging glucose concentration based on the observed colors, thereby enhancing diagnostic capabilities (Figure 4.7)

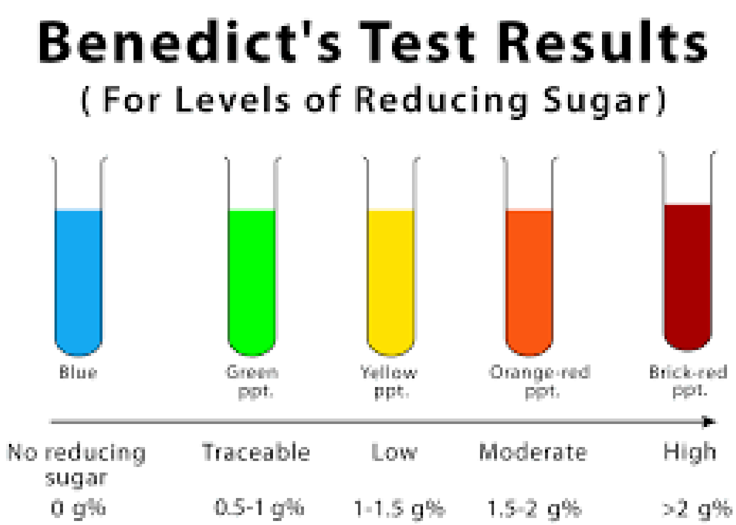


Figure 4.7 Percentage of sugar presence based on Benedict’s test

4.4 Software Implementation

The MIT app inventor software was used to build the application. The description for the implementation of the software is given below.

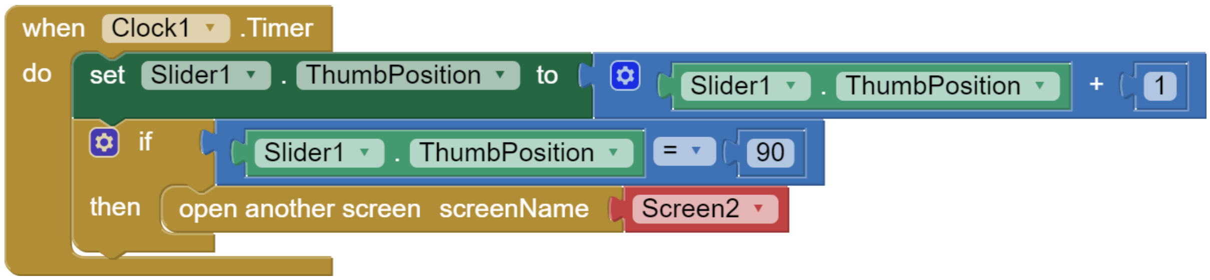


Figure 4.8 Block code for Opening interface

Figure 4.8 represents the code for opening interface where there is a slider which moves from left to right and the user enter into another interface of choosing option between “Using Device” or “Using Camera”.

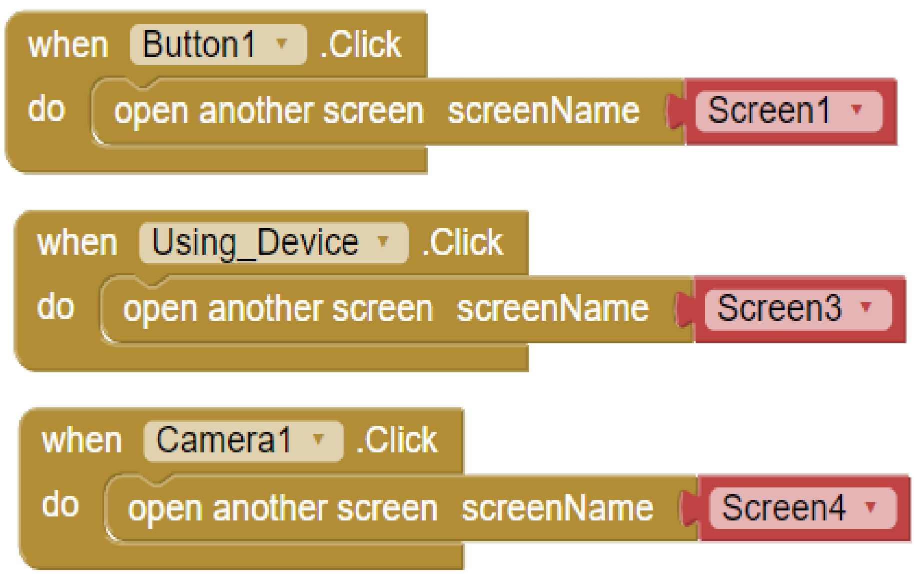


Figure 4.9 Block code for screen change

Figure 4.9 represents the code for screen change. In this code a button option is used to create two buttons named "Using Device" or "Using Camera". Here user can choose any of the option according to their need.

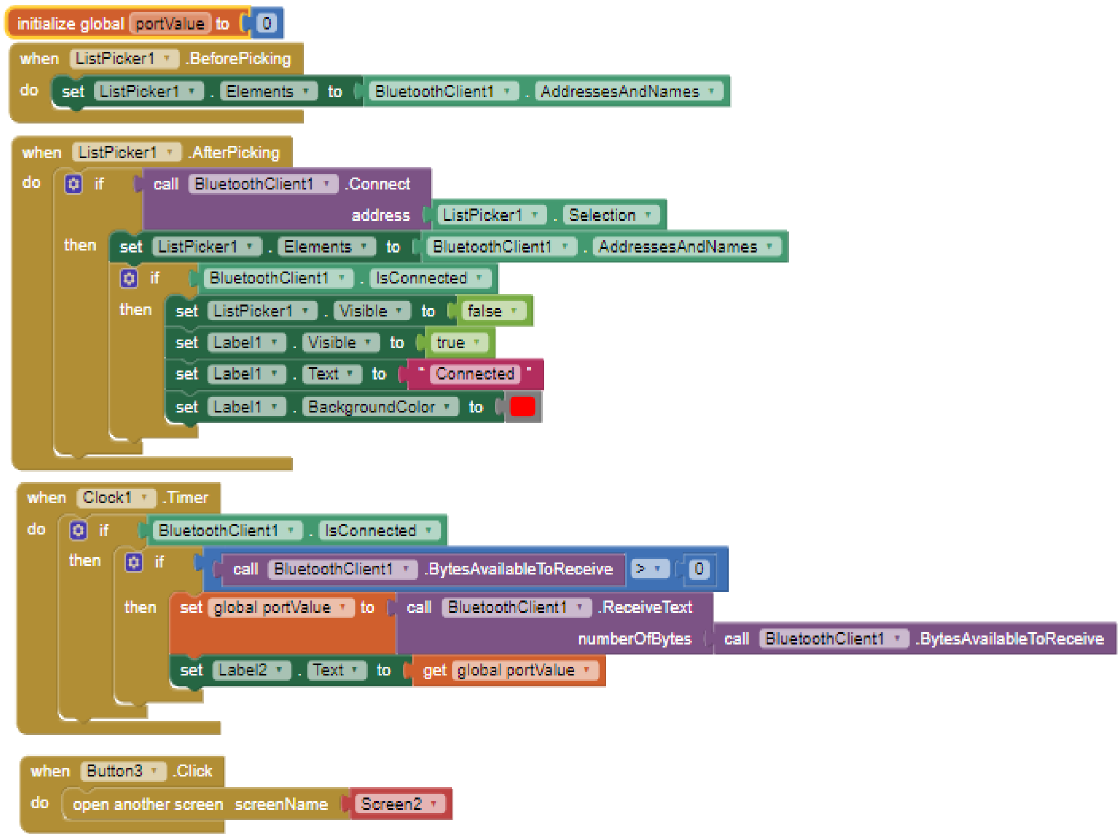
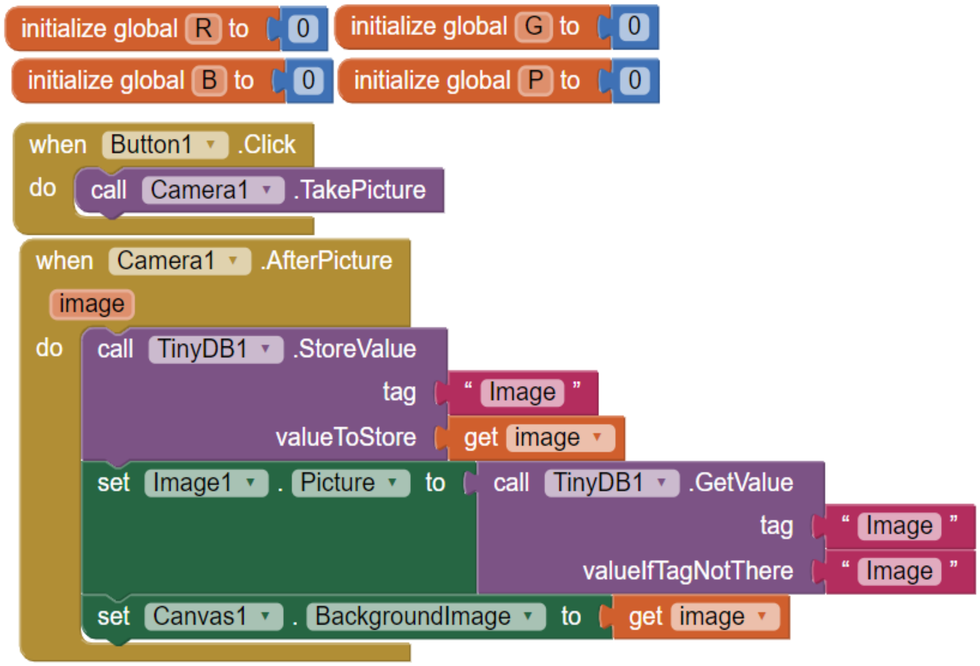
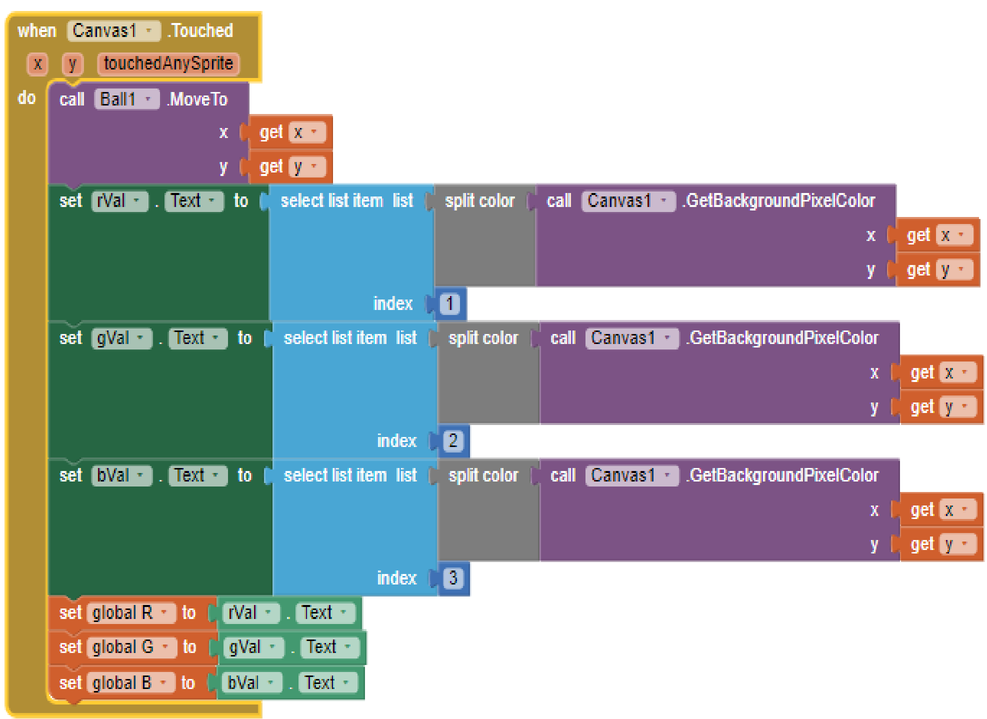


Figure 4.10 Block code for " using telechroma device"

Figure 4.10 represents the block code for connecting the Telechroma Device to the phone via Bluetooth from which data has been come to analyze the color and concentration of the solution. In this code Bluetooth connection has been demonstrated in the app for scanning the near wise device to collect data from the device and give the appropriate result.


initialize global R to 0
initialize global G to 0
initialize global B to 0
initialize global P to 0
when Button1 .Click
do call Camera1 .TakePicture
when Camera1 .AfterPicture
image
do call TinyDB1 .StoreValue
tag "Image"
valueToStore get image
set Image1 . Picture to call TinyDB1 .GetValue
tag "Image"
valueIfTagNotThere "Image"
set Canvas1 . BackgroundImage to get image


when Canvas1 .Touched
x y touchedAnySprite
do call Ball1 .MoveTo
x get x
y get y
set rVal . Text to select list item list split color call Canvas1 .GetBackgroundPixelColor
x get x
y get y
index 1
set gVal . Text to select list item list split color call Canvas1 .GetBackgroundPixelColor
x get x
y get y
index 2
set bVal . Text to select list item list split color call Canvas1 .GetBackgroundPixelColor
x get x
y get y
index 3
set global R to rVal . Text
set global G to gVal . Text
set global B to bVal . Text

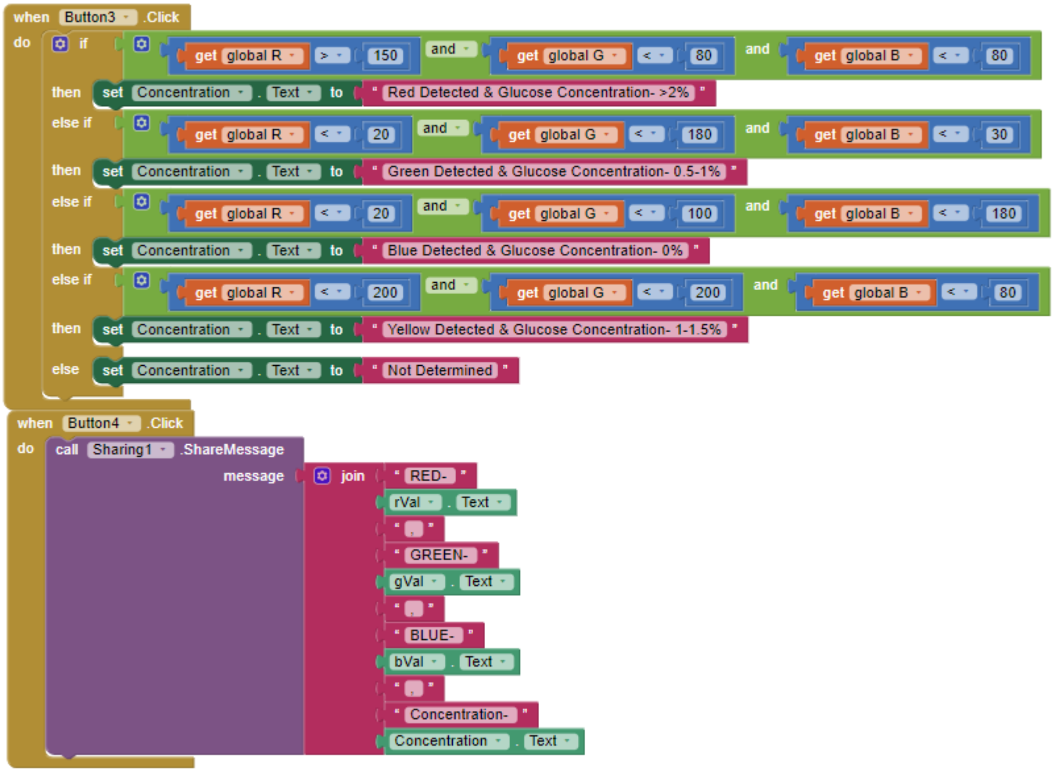


Figure 4.11 Block code for using Mobile Camera

Figure 4.11 represents block code for initiating an option of mobile camera to capture the image of the solution and provide results according to the color of the solution. The algorithm provided in Al blocks will calculate the red, green and blue value or the RGB value of the exact point of the image from that image. This works by taking the pixel point of the exact point where the ball is on the image. According to RGB value of that solution it will provide concentration of glucose. Another button named “Share Info” is used to share the RGB values of the color image to health consultants or professionals. It will share the message via WhatsApp, Messenger, Email, Messaging, etc.

Chapter V

Results and Discussion

5.1 Results

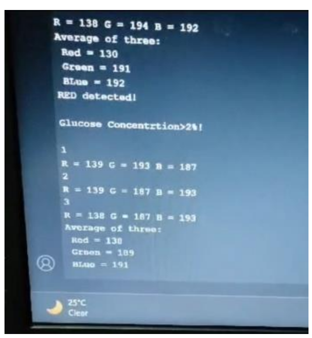
After completing the implementation of both the hardware and software components, the results were achieved, analyzed and discussed.

5.1.1Telechroma Device Output

Figure 5.1 illustrates all the hardware implementation results. Figure 5.1(a) shows the “Telechroma” device. Figure 5.1(b) represents the picture of sample test 1 which is basically a red color sample. This color is detected and according to this color the glucose concentration in urine is shown >2% in figure 5.1(c). And again, sample test 2 is taken which is illustrated in figure 5.1(d) which is basically a blue color sample. This color is detected and according to this color the glucose concentration in urine is shown 0% in figure 5.1(e). And at last, sample test 3 is taken which is illustrated in figure 5.1(f) which is basically a green color sample. This color is detected and according to this color the glucose concentration in urine is shown (0.5-1)% in figure 5.1(g). All these data have finally passed to mobile phone through Bluetooth.

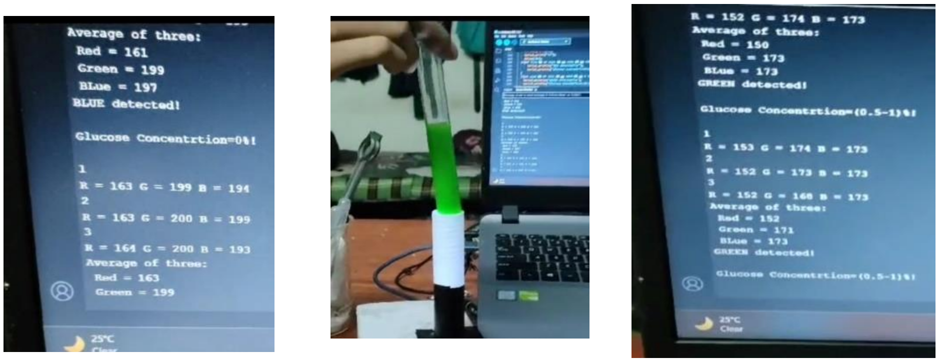
(a) Device (Telechroma)

(b) Sample test 1



(c) Sample test result 1

(d) Sample test 2

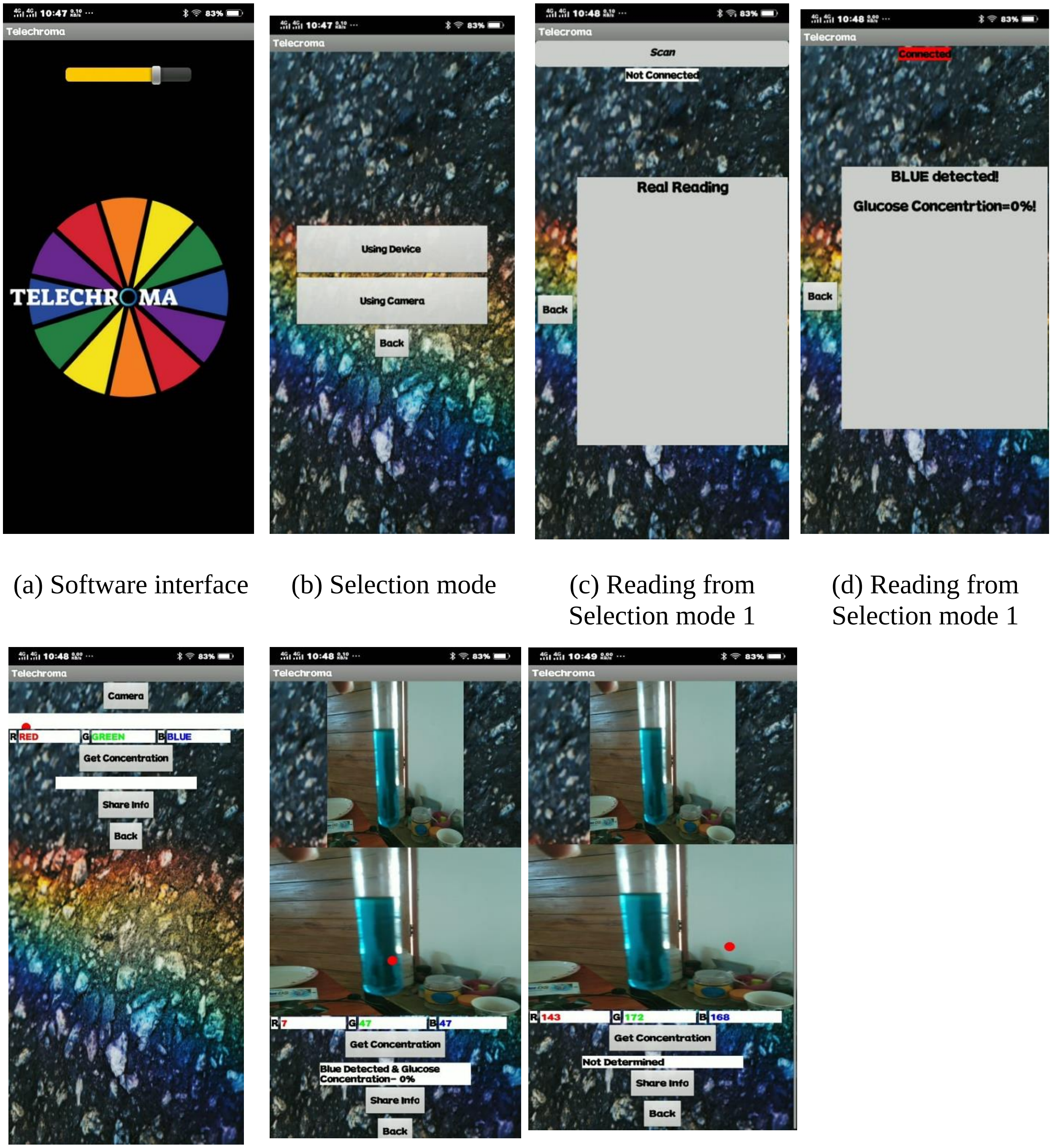


(e) Sample test result 2 (f) Sample test 3 (g) Sample test result 3

Figure 5.1 Hardware implementation result

5.1.2 Software Output

Figure 5.2 illustrates all the software implementation result. Figure 5.2(a) shows the picture of software interface. Figure 5.2(b) represents the two-selection mode of the app (i) Using Camera & (ii) Using Device. If the 1st option is chosen then an interface will come that shows scanning option for connecting the Telechroma device to the mobile which is shown in figure 5.2(c). If a blue color solution is put on the Telechroma device then the result will pass to the mobile phone through Bluetooth and the concentration value will visualize in the phone which is shown in 5.2(d). If the 2nd option is chosen then an interface will come that shows the camera option, RGB value box and concentration of the urine sample box which is shown in figure 5.2(e). If a blue sample is captured via mobile phone and pointed the blue color then it will show the RGB value of that solution with a message that blue is detected and the concentration is 0% which is basically represented in figure 5.2(f). If another color is pointed out except blue solution in the image, it will show the RGB value of that color with a message that "Not Determined" which is basically illustrated in figure 5.2(g).



(a) Software interface (b) Selection mode (c) Reading from Selection mode 1 (d) Reading from Selection mode 1

(e) Reading from Selection mode 2 (f) Reading from Selection mode 2 (g) Reading from Selection mode 2

Figure 5.2 Software implementation result

The results after implementation in both device and camera modes showed almost estimated values. Table 5.1 shows the obtained results of glucose concentration in urine for different colors.

Table 5.1:Results analysis

Selection Mode	Color of the Solution	RGB Value of the Color	Detection (Yes/No)	Concentration
Using Device	Red	R=130	Yes	>2%
		G=191		
		B=192		
	Blue	R=161	Yes	0%
		G=199		
		B=197		
	Green	R=152	Yes	(0.5-1)%
		G=171		
		B=173		
	Yellow	R=133	Yes	(1-2)%
		G=168		
		B=170		
Using Camera	Red	R=129	Yes	>2%
		G=195		
		B=190		
	Blue	R=163	Yes	0%
		G=197		
		B=194		
	Green	R=127	Yes	(0.5-1)%
		G=196		
		B=190		
	Yellow	R=135	Yes	(1-2)%
		G=165		
		B=172		
		R=115	No	-
		G=130		
		B=155		

5.2 Calculation of Accuracy and Error

Using Device:

Correct Detections: 4 (Red, Blue, Green, Yellow)

Incorrect Detections:0

Total Detections: 4

Accuracy:

Accuracy = Number of correct detection/Total number of detections

Accuracy = 4/4= 1.0

Error:

Error = 1 - Accuracy

Error = 1 - 1.0 = 0.0

Using Camera:

Correct Detections: 4 (Red, Blue, Green, Yellow)

Incorrect Detections: 1 (No detection for the last set of RGB values)

Total Detections: 5

Accuracy:

Accuracy= Number of correct detection/Total number of detections

Accuracy = 4/5 = 0.8

Error:

Error = 1 - Accuracy

Error = 1 - 0.8 = 0.2

Summary:

Using Device:

Accuracy: 100%

Error: 0%

Using Camera:

Accuracy: 80%

Error: 20%

5.3 Discussion

Telechroma has marked a significant milestone in the field of healthcare diagnostics and telemedicine, as it successfully implemented the planned workflow to achieve its core objectives. The project's workflow allowed us to collect biological samples, primarily urine, and utilize colorimetric analysis to determine glucose concentrations in these samples. The results of this analysis were then integrated into the application interface, thereby providing healthcare professionals and patients with a user-friendly platform for real-time data interpretation and management.

However, our journey towards the successful completion of this project was not without its share of challenges and obstacles. Limited resources constrained our ability to collect a more diverse set of samples, and we were only able to obtain urine samples from a healthy subject and a diabetic patient. While these samples served our purpose, a broader range of samples would have further enriched our findings.

Another challenge we faced was related to the Bluetooth module, which initially exhibited instability. To overcome this issue and ensure a reliable connection, we had to employ soldering techniques to strengthen the connections, thus making it more robust.

Modifications to the project's code were also a necessity. As the sensor values were fluctuating, we had to take the average of the values. The initial application interface did not function as expected, necessitating a series of block changes in the MIT app inventor to ensure that it performed as intended. Additionally, we had to adapt the code to accommodate alternative methods, especially when the camera captured the entire sample, instead of the specific area of interest.

Upon analyzing the results of the project, we found that the data closely approximated the ideal outcomes. In case of using device results, the accuracy was 100% ,but in case of camera there showed some errors decreasing the accuracy to 80%. These deviations can be negligible in a sense but needs to be refined in the future.

In summary, Telechroma overcame challenges through innovation and problem-solving. The successful integration of the analyzer with telemedicine components demonstrates the potential to enhance healthcare diagnostics and accessibility. As we look to the future, there are opportunities for further enhancement. Additional resources can be incorporated to improve system robustness and accuracy. Moreover, a more sophisticated and user-friendly interface for the telemedicine application could greatly benefit from these advancements. Telechroma definitely represents a significant step toward improving healthcare and expanding the horizons of telemedicine.

Chapter VI

Conclusion and Future Work

6.1 Conclusion and Future Work

In conclusion, the development and implementation of Telechroma, the smart colorimetric analyzer, marks a significant step forward in the realm of healthcare diagnostics and monitoring. This project successfully demonstrated the feasibility of utilizing a colorimetric analysis system to detect subtle color changes in biological analytes, with a specific focus on urine and its diagnostic significance, thereby making a valuable contribution to the field of telemedicine.

As with any innovative venture, there exists opportunities for further enhancement and expansion. In the future, the hardware components of Telechroma can be further refined and made more robust to ensure durability and reliability in various healthcare settings. The software component can be enriched with additional features and functionalities, offering a more comprehensive and user-friendly interface for both patients and healthcare professionals.

With increased financial resources, the possibilities for improvement and innovation are vast. Integrating advanced components such as Raspberry Pi, a spectrometer module, automated sample handling systems, and environmental monitoring sensors can elevate the capabilities of Telechroma. These enhancements will not only enhance the accuracy and versatility of the system but also pave the way for a more seamless and integrated telemedicine application.

In essence, the successful development of Telechroma opens the door to a promising future of healthcare diagnostics and telemedicine. Through ongoing research, development, and investments, we can harness the full potential of this technology, ultimately realizing its potential to significantly benefit the telemedicine field and improve healthcare accessibility and quality.

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