DESIGN AND DEVELOPMENT OF AN INTERNET OF THINGS BASED GLUCOMETER WITH WIRELESS TRANSMISSION

Abstract

Diabetes is one of the top non-communicable illnesses of public health importance. 6.4% of world population is reported to have diabetes mellitus with the figure, feared to double by 2040. Nigeria has estimated 1.6 million cases in 2015, which ranked her the third diabetes endemic country in Africa. Diabetes complication is a known leading cause of the disease high mortality rates and healthcare burden on developing economies. Daily monitoring of blood sugar levels, however, is an effective way to prevent diabetes complications. Glucometer is a simple device used for blood glucose monitoring. The aim of this study was to design and use locally sourced materials to fabricate a cheap digital glucometer that will be able to measure blood glucose levels and sends a distress signal to medics and caregivers via wireless transmission.The method employed includes programming, calibration, assembling, component testing, and the overall device test. The device is equipped with an Atmega32 microcontroller, One-Touch Ultra glucose sensor, a GSM module, emergency button, and internet of things (IoT). Our device and a conventional device (Accuchek) were used to measure the blood sugar level of 200 individuals in groups of 5, the data were analyzed using SPSS2.0 and Microsoft Excel 2010.The p-value was (>0.05) indicating no significant difference between the data generated by our device and the conventional glucometer, while the coefficient of determination (R^2) was 0.9838. From the results above, we conclude that our fabricatrd device is effective and reliable.

Key words: Glucometer; Diabetes; Internet of things; GSM module; blood sugar level; sensor

1.0 Introduction

1.1 Diabetes

Diabetes is a life-threatening condition that occurs when blood sugar levels become too low (hypoglycaemia) or too high (hyperglycaemia) [1, 2]. Hypoglycaemia occurs when the blood glucose level is <70mg/dl [3]. It might occur due to much intake of insulin or when activity level is higher than calorie intake, or a lack of nutritious diet [4, 5].

Paleness, tachycardia, shallow breathing, and weariness are all symptoms [6]. It is also known as insulin shock. Hyperglycaemia, however, occurs when fasting blood sugar levels are >130 mg/dl or when random blood sugar level are >180 mg/dl about two hours of meal [7], due to the body lacking insulin to make glucose available, hence, begins to burn fat for energy. Frequent urination, dry mouth, etc are some symptoms [8]

The three main classes of diabetes include: Type 1 Diabetes mellitus (T1DM), Type 2 Diabetes mellitus (T2DM), and Gestational Diabetes Mellitus (GDM). T2DM accounts for roughly 90-95% of diabetes cases [9, 10] . It is a non-insulin-dependent DM and has been associated with a combination and interplay of genetic, physiologic, and environmental factors such as age, obesity, lack of physical activities and lifestyle factors [11’ 12]. It is also associated with various macrovascular complications, known to be the major causes of morbidity and mortality among those living with diabetes [13, 14]. T1DM is an autoimmune condition mediated by the destruction of insulin-producing β-cells in the pancreas [8]. Around the world, diabetes mellitus is reported to contribute considerably to the high mortality rate from non-communicable diseases [14] as a result of immune deficiency [15, 16, 17]. Currently, about 6.4% world - wide live with diabetes mellitus and by 2040, the number may double. In Nigeria, about 1.6 million cases of the disease was reported in 2015 making her one of the most endemic country for diabetes in Africa [13, 18, 7]. There is no cure for diabetes, although, life style changes and periodic blood glycaemic checks are very important in the management of the disease [19, 20].

1.2 Glucometer

A glucometer, also called blood glucose meter, is a compact, portable electronic device which is frequently used to measure blood glucose concentration [21, 22]. It is particularly helpful in diabetic management since it could be used to measure blood glucose concentrations anywhere and at any time of the day. The Glucose meter includes a test strip that the patient puts into the meter, and measures blood glucose from a very small sample of blood obtained by pricking the finger with a lancing device, the blood droplet is loaded onto the test strip, and after a few seconds, an immediate measurement of the sample glucose levels is given out on the display unit in mmol/l or mg/dl [23, 24].

Our device consists of a glucose meter, and an installed Internet of Things (IoT) - based communication device adapted for communication with emergency contacts. This revolves around telemetry in the sense that a distress call can be sent and feedback given. The device would provide constant and convenient assistance, such as in making complex decisions when extremely high or low value is given. In an emergency, the diabetic patient may not be able to access needed help. There is a need, therefore, to develop a device that will readily alert medics and caregivers when such situations occur. This gadget, however, allows its user to quickly alert their emergency contact in the case of an emergency, through an SMS (Short Messaging System) and/or with an alarm which is activated by a push of a button to request their attention.

2.1 Materials

Table 1 List of Electronic Components

S/NO	Components Description	Quantity	Specification
1	Microcontroller	1	Atmega32, 20mA per bit terminal, 5V, 40pin terminals.
2	IC socket	1	40pin

3	Resistor	3	1K and 10k, and 330ohms 0.5W
4	Capacitor	3	22pF/35V and 1000uF
5	Test Socket	1	OneTouch Ultra
6	Transistor	1	BC547
7	Liquid Crystal Display	1	LM3229, 5V
8	Vero board	1	12 *30 holes
9	Lead	10Yards	
10	Jumper Wire	2 Yards	RJ45
11	Transformer	1	220V-12V AC
12	Variable resistor	2	10k, 0.5W
13	SPST switch	2	10A, 220V
14	Regulator	1	7805 types, 5V,1A
15	Diode	4	1N4007,1A
16	Light Emitting Diode (LED)	1	5mm, 1.5V-3V, 20mA
17	Switch	2	Push to make (Micro)
18	Crystal oscillator	1	20MHz

2.2 Methods

System Block Diagram and Description

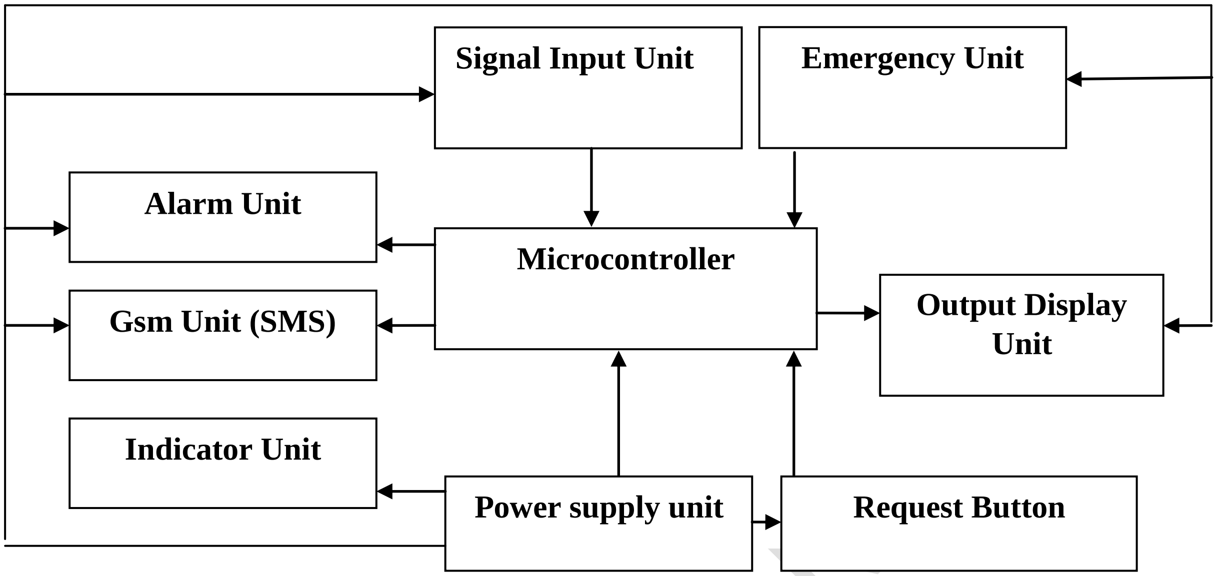


Figure 1: Block Diagram of the Glucometer

Signal Input Unit

This section ensures that the microcontroller receives the converted voltage signal to be monitored from the test strip. This is achieved by applying a bias voltage on the test trip electrodes which reacts with chemicals on the test strip and current proportional to the glucose in the blood is measured as a result of the electrochemical reaction on the test strip. Electrochemical test strips have electrodes where a precise bias voltage is applied with a digital-to-analog converter (DAC), and a current proportional to the glucose in the blood is measured as a result of the electrochemical reaction on the test strip. The current is converted to a voltage for easy measurement with an analog-to-digital converter (ADC). If the input sensor receives signal current, it directly sends the signal to the microcontroller. The microcontroller is left to make decisions base on the received signal. The process used in acquiring this data is electrochemical and the reason for choosing this particular type is because it offers excellent and high accuracy and stable readings.

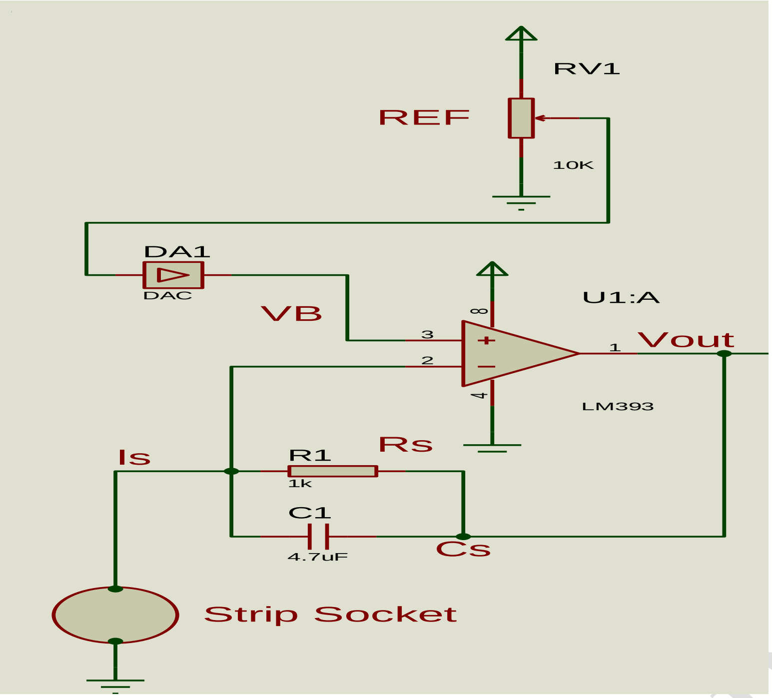


Figure 2: Glucose Level Input Signal Converter

2.2.2 Design Calculation for Voltage output

The output voltage that enters into the microcontroller can be calculated with the following formula:

$$V_{OUT} = V_B + I_S * R_S \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.1)$$

Where V_{OUT} is the output voltage that is to enter the microcontroller for reading, V_B is the reference voltage, I_S is the input current generated by the test strip, and R_S is the source resistance.

$V_B = 2.5V$

$R_S = 1000$ ohms and

$I_S = 20uA$ (assumption) this value depends on the current received from the test Strip.

Therefore;

$$V_{OUT} = V_B + I_S * R_S$$

$V_{OUT} = 2.5 + (20*10^{-6}) * 1000$

$\mathbf{V_{OUT} = 2.52V}$

Alarm Unit

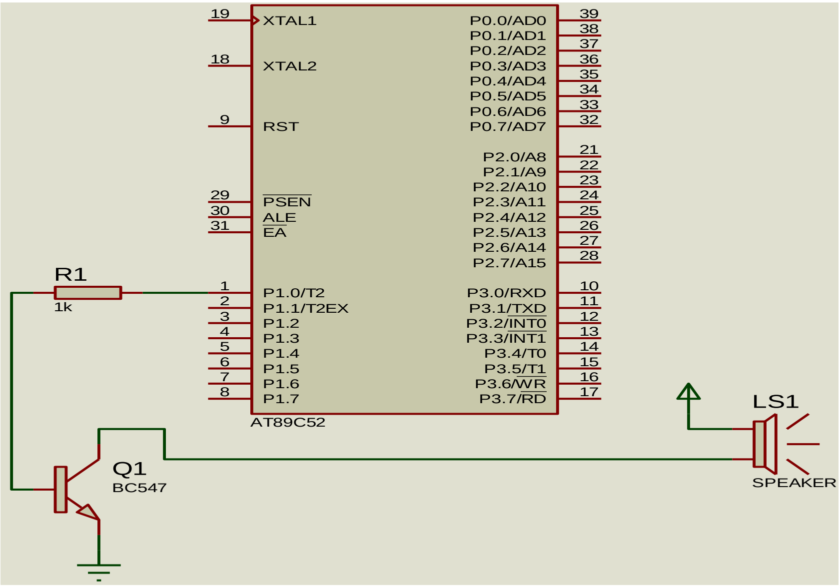


Figure 3: The Alarm Unit

2.2.3 The calculation for Transistor Base Biasing current

There is a need to control the specific current that enters the base of a transistor. This helps to maintain and control the amount of current entering the transistor base since it requires less current. From the circuit diagram above, we established a V_{cc} supply of +5v.

Using

$IB = (VCC – VBE) / RB$.. (3.2)

Where V_{cc} is the microcontroller output voltage that enters the transistor through a biasing resistor, V_{BE} is the base-emitter voltage which is a voltage drop of 0.7V across the base-emitter of the terminal transistor.

Data giving:

V_{CC} = 5volts, the microcontroller voltage

R_B = 1000 ohms, the base resistor

V_{BE}=0.7volts

Therefore

$$IB = (VCC – VBE) / RB$$

$I_B = 5 – 0.7 \div 1000$

$I_B = 4.3 \div 1000$

$\mathbf{I_B = 4.3mA}$

Power supply unit

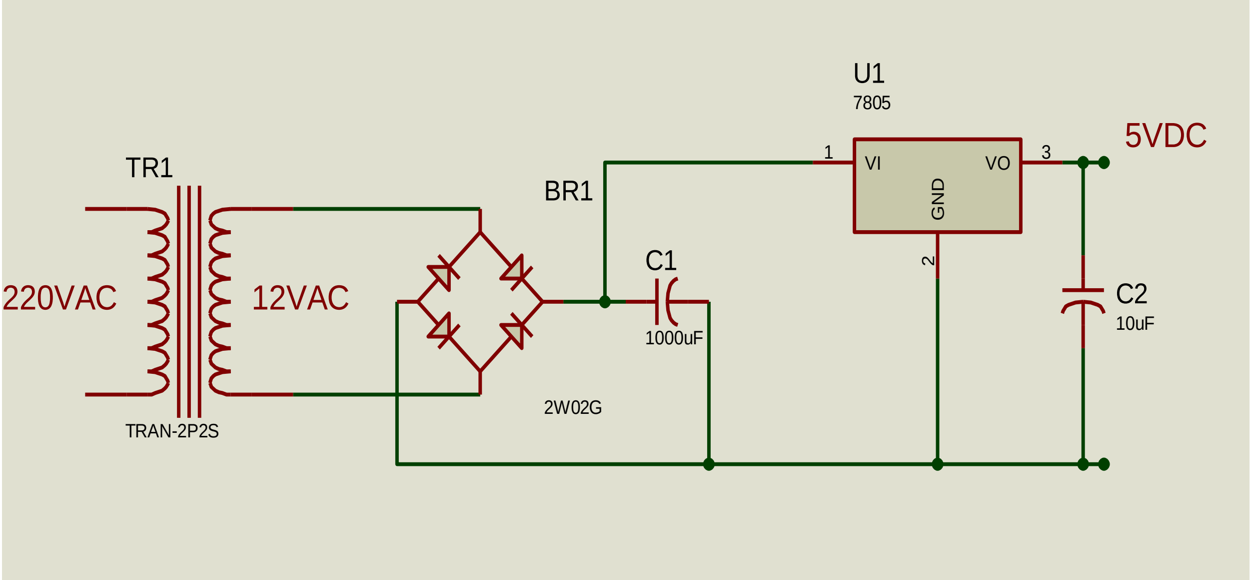


Figure 4: The Power supply unit

2.2.4 Data Analysis

We used SPSS20.0 software for windows SPSS, 2011 to analyze the data.. The reliability correlation was determined using Microsoft Excel, 2010.

Programming Stage

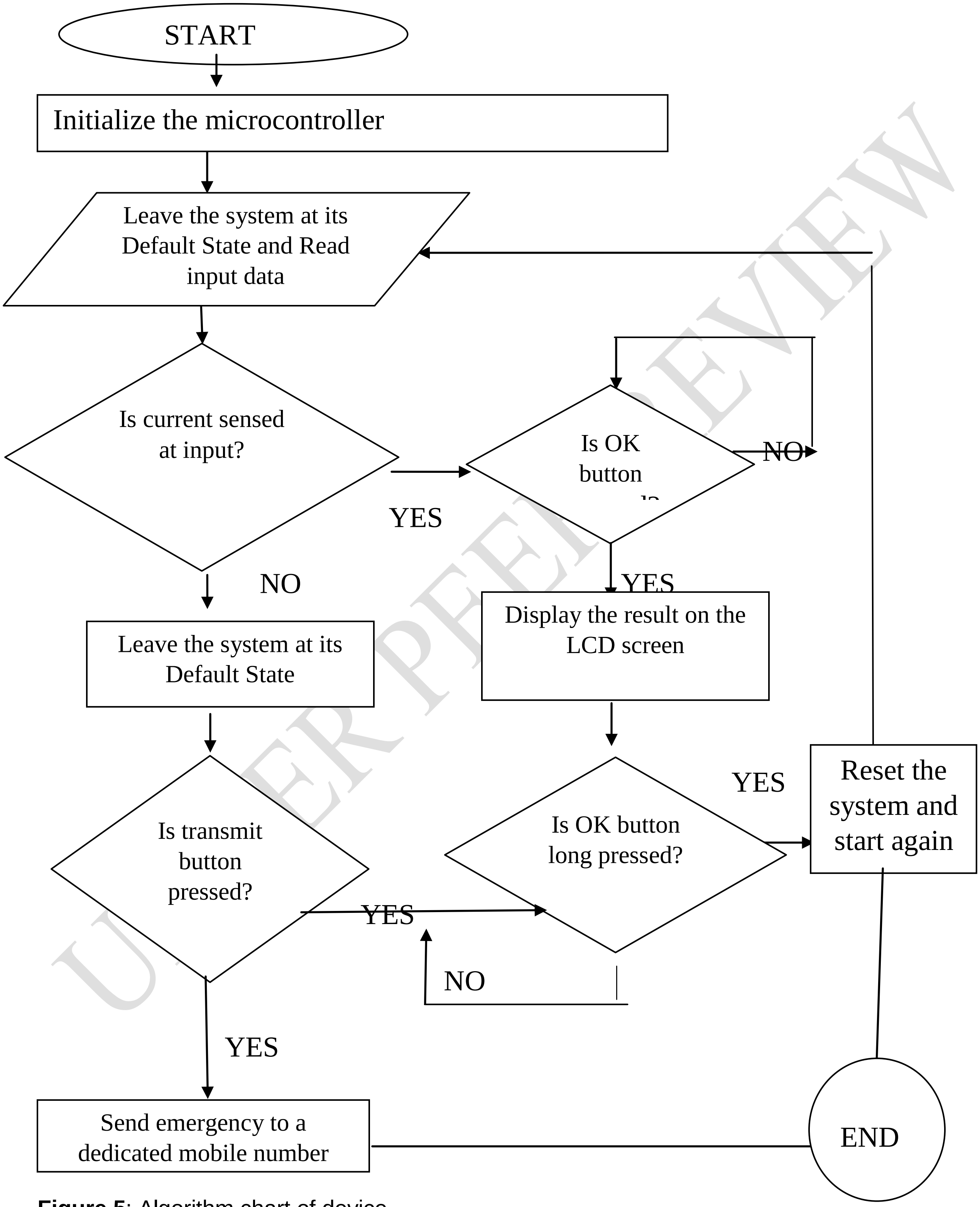


Figure 5: Algorithm chart of device

3.1 Results

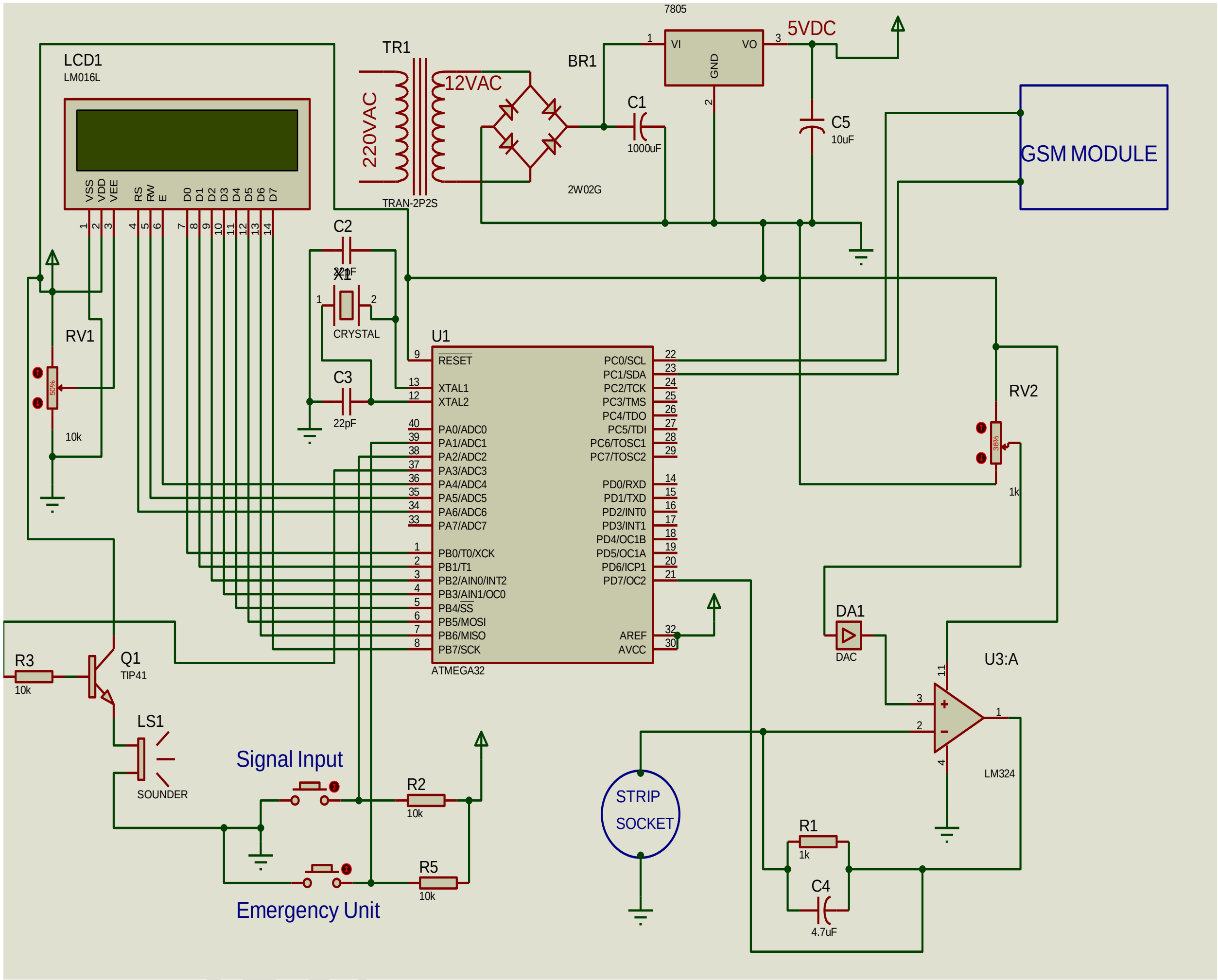


Figure 6: Circuit diagram of the Glucometer with GSM module

Usage Testing

The emergency button of the glucometer was tested and it gave the following result

IHETU CHIMDINMA NEEDS URGENT ATTENTION

IHETU CHIMDINMA NEEDS URGENT ATTENTION

9:37 PM

IHETU CHIMDINMA NEEDS URGENT ATTENTION

Plate 1: Screenshot showing emergency message

Plate 2: Fabricated Glucometer displaying blood sugar result

Table 2: Mean and standard deviation in (mg/dl) of blood sugar measurements from conventional and our fabricated glucometer

Patient Groups	Fabricated Model Result (mg/dl)	Conventional Model Result (mg/dl)
1	111.18±0.3	114±0.3
2	125.68±0.3	127±0.4
3	125.24±0.5	130±0.2
4	105.63±0.4	100±0.5
5	117.34±0.2	119±0.3

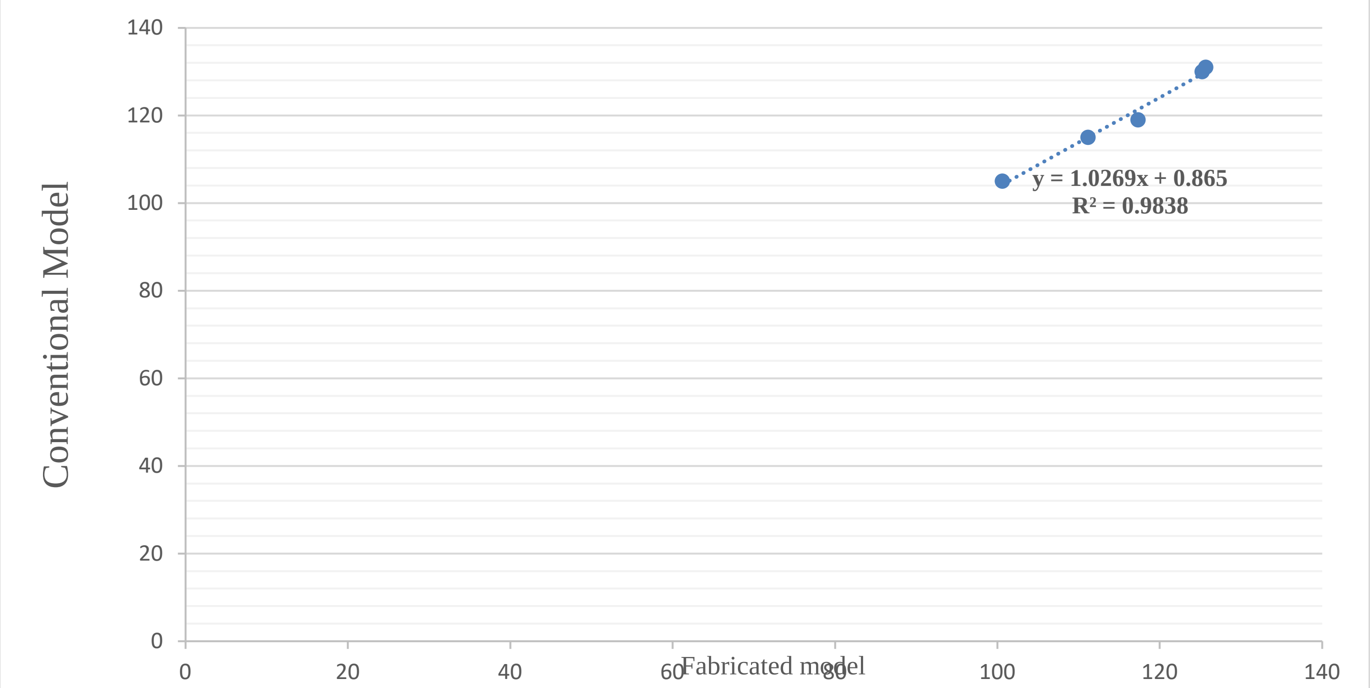
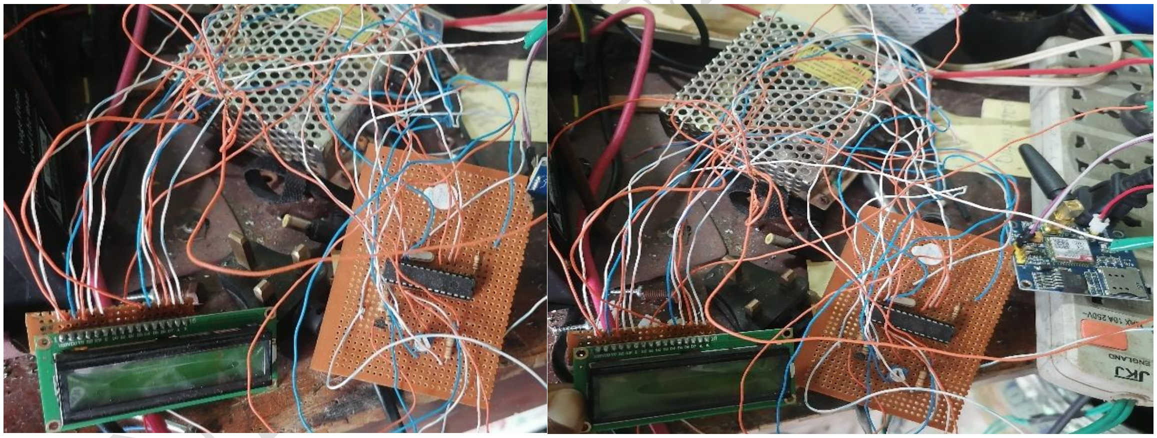


Figure 7: Correlation model of fabricated model result(mg/dl) against standard model result(mg/dl)



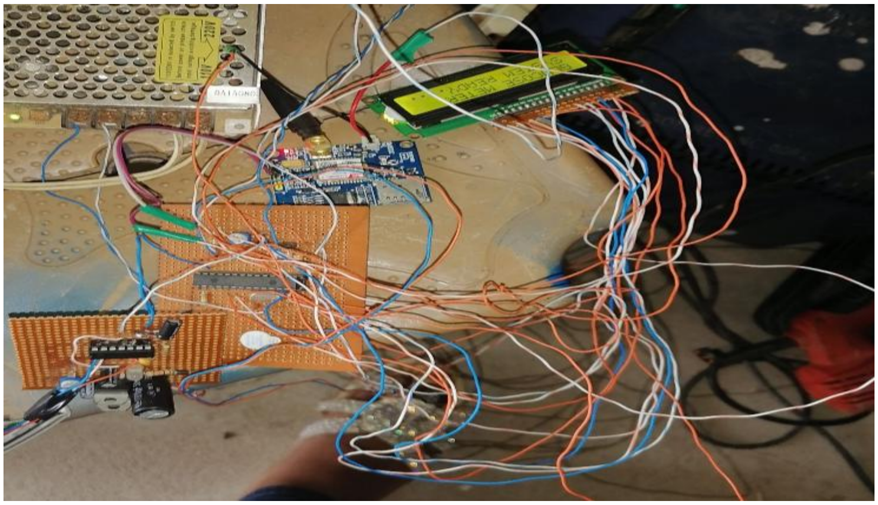


Plate 3 Picture of components

System Cost Evaluation

The cost of all the materials used in the development of the new system is reviewed

The conventional glucometer compared with this work is the Accuchek glucometer, the Accuchek glucometer, the strip, and the lancet goes for #18,000 while the fabricated model costs #16,260.

The cost estimation is given as

$$\frac{Conventional\ cost - Fabricated\ cost}{Conventional\ cost} \times 100$$

$\frac{18000-16260}{18000} \times 100 = 9.67\%$

The result of the cost analysis shows that the fabricated glucometer is 9.67% less expensive compared to the conventional design. It also possesses added features such as IoT (Internet of Things) and an emergency button which is not found in the conventional glucometer.

3.2 Discussion

We developed using an ATMEGA32 microcontroller and a OneTouch Ultra biosensor test socket, GSM module and LCD, a glucometer that was able to measure the blood glucose level (see plate 2) and at the same time send critical results to the medic and in the case of emergency, alert the medic or care giver when a button is pressed (see plate 1). The microcontroller serves as the interface between the test strip bio-sensor [25, 26, 27], GSM module, and LCD to check the blood sugar and display the result at a press of a button [28, 29, 30].The available glucometers are focused on measuring blood sugar only [31, 32], however, we used the Arduino Uno microcontroller which did not have any feedback mechanism but worked with a USB connection, and the design by [21] as modified by [33] which used Bluetooth connection, to develop our device, which is capable of sending an SMS message to any phone (see plate 1). Previous designs lack that capability and do not have emergency functions that can be activated in cases of emergency [34, 35], as does our design.

The fabricated glucometer was be used to test for fasting blood sugar and random blood sugar, it gave reliable results when compared with a conventional glucometer (see table 2). It sends out critical results of hyperglycemia for blood sugar >150mg/dl, whenever the glucometer recorded values outside the normal range, it sends an emergency message to an emergency contact via a press of a button (see plate 1). BEME (Bill of Engineering Measurement and Evaluation) analysis was carried out and the result showed that the fabricated glucometer was less expensive than the conventional one, with added features such as IoT (Internet of things) and emergency alarm button (see system cost evaluation). Comparing our prototype with a conventional glucometer (Accu-chek), by using both to measure the blood sugar level of 200 different persons and analysing the data generated using SPSS2.0, the p-value was (>0.05) indicating no significant difference between the data generated by our device and the conventional glucometer. Its reliability was also determined, using Microsoft Excel; the result gave the coefficient of determination R^2 of 0.9838, implying that our design is effective and reliable (see figure 7).

Conclusion

The integration of mobile telecommunications into medical care has helped in the effective and cost-effective communication between patients and their health care providers, leading to reduced hospital visits and long waiting hours. In this research, a digital glucometer with wireless transmission of critical results and the alert system was fabricated, this work was achieved using an ATMEGA32 microcontroller, GSM module, and LCD. The microcontroller serves as the interface between the components.

Several systems and device tests were carried out on the fabricated digital glucometer, such tests include reliability test, power test, resistor test, and so on. To determine its reliability, the fabricated model results were compared to the conventional model results with a coefficient of determination R^2 of 0.9838. It is also 9.67% cheaper than the conventional model which goes to show that the model is reliable, cost-effective, and can be used to conduct diabetic tests effectively

Every critical result recorded by the glucometer is sent to the healthcare provider which is stored in the patient database.

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