EMITTER International Journal of Engineering Technology
Vol. 11, No. 1, June 2023, pp. 76~88
DOI : 10.24003/emitter.v11i1.766

Implementation of blood Glucose and cholesterol monitoring device using non-invasive technique

Shubha B[1], Anuradha M G[1], Poornima N[1], Suprada H S[1], Prathiksha R V[1]

[1]Department of Electronics and Communication, JSS Academy of Technical Education, Bengaluru
Corresponding author: shubhab@jssateb.ac.in

Received January 21, 2023; Revised April 7, 2023; Accepted June 5, 2023

Abstract

Invasive testing of glucose and cholesterol levels in the blood is the most prevalent procedure, which is uncomfortable, expensive, and risky since it can spread infections and harm skin cells. Diabetes and cholesterol are two of the most common diseases in the world, and they require constant monitoring to avoid health issues and organ damage. As a result, a non-invasive approach will allow for more regular testing and painless monitoring. The blood glucose and cholesterol levels can be assessed using the principle of reflecting and refractive properties of NIR light source against blood components. The MAX30100 sensor circuit gives SPO2 (Saturated Peripheral Oxygen Level) and BPM (beats per minute, or heart rate) information to the regression model, which is used to forecast blood glucose and cholesterol levels. The polynomial regression model is trained using preset datasets, and the trained model yields regression co-efficient values. For the fresh sample inputs from the sensor, the co-efficient values are used to estimate the new needed parameter value. The projected blood glucose and cholesterol levels are displayed on the LCD Display and delivered through Bluetooth HC-05 module via Serial communication to the mobile application.

Keywords: Blood glucose, Cholesterol, Non-Invasive testing, Regression analysis, Spectroscopy.

1. INTRODUCTION

Cholesterol is found in every cell in the body and is produced by the body or consumed through dietary food, with lipoproteins transporting it through the bloodstream. The cholesterol can be transported by two types of lipoproteins viz low-density and high density lipoproteins referred as LDL and HDL respectively. It's crucial to keep both types of lipoproteins at the right levels, because high LDL levels signal a higher risk of heart disease, but high HDL levels indicate a healthy heart. VLDLs, or very low-density lipoproteins, transfer cholesterol from the liver to the body's organs and tissues. Total cholesterol is made up of LDL cholesterol, HDL cholesterol, and VLDL cholesterol. Ideal cholesterol level should be less than 200mg/dL according to the clinical investigation. The cholesterol level of more than 240 mg/dL is harmful for the human body.

Diabetes mellitus (DM), commonly referred to as Diabetes, is a prominent cause of death and morbidity around the world. Our blood sugar levels are controlled by the insulin hormone. A diabetic's body, on the other hand, either does not generate enough insulin or does not utilise it properly. The blood sugar level rises as a result. This causes a plethora of issues, including the degeneration of various organs in the body. Type 1 diabetes, type 2 diabetes, and gestational diabetes are the three kinds of diabetes.

Type 1 diabetes is caused by the body not producing enough insulin, but Type 2 diabetes is caused by the body producing too much insulin that is not used properly. Gestational diabetes is more common in pregnant women. The three main categories of blood glucose levels are hypoglycemia, normal blood glucose level, and hyperglycemia. Blood glucose monitoring on a regular basis can help to lower the risk of fatal diabetic complications.

Invasive, Minimally Invasive, and Non-invasive are the three systems available. An invasive method is a medical procedure that involves cutting or puncturing the skin or inserting instruments into the body to invade or enter the body. In a minimally invasive procedure, tiny incisions are produced with the help of small flexible instruments rather than a huge opening. There is less pain and a faster healing time because the incisions are smaller. Without cutting or inserting tools into the body, the skin is not damaged in the Non Invasive approach. The main distinction between invasive and non-invasive tests is that invasive tests entail cutting or entering a body part with medical equipment, whereas non-invasive tests do not.

The invasive method is the traditional and conventional existing method which includes tests like biopsy, endoscopy, cryotherapy etc which are carried out by medical providers using instruments that cut the skin. There are many drawbacks of the invasive procedure as it is painful, expensive and causes discomfort and damage to the patient skin leading to infections and the usage of invasive technique for pregnant woman increases the chances of abortion and mental stress. Thus, puncturing of skin is not an advisable method for continuous monitoring. A Non Invasive system which is simple, reliable and painless due to absence of incision of skin surface can overcome the drawbacks of an invasive system.

2. RELATED WORKS

The work by Tuhong Zheng et.al [2], suggested a hardware framework that consists of NIR unit transmitter, receiver, and signal amplifier. NIR region was chosen because of its high S/N ratio and low absorbance in skin tissue and its non-destructive nature to the human skin cells. Arduino Uno is used as the CPU for data processing and LCD Display is used to display real time blood glucose values which is interfaced with the Arduino. Mobile application was developed to monitor the changes from time to time.

Bluetooth module was also used to connect the Arduino and mobile application.

Although the device can measure blood glucose levels, the accuracy of the data can be enhanced by reducing the effect of the factors such a finger thickness and physiological variances.

The work carried out by I.M.M. Yusoff et.al [3] suggests that noninvasive detection of lipid molecules (lipoproteins) in blood can be used to predict cholesterol levels. The NIR spectrum was chosen because of its tight spacing, which reduces light interference inside the bloodstream. Given the different aspects of solute concentration in the blood, the absorbance property of lipid molecules is shown to be most efficient at around 1720nm. The photodiode used for NIR reception would be InGaAr, which has a high response for IR wavelengths.

The work by Anis SN [5], suggests that Glucose absorption is maximum at 940nm, and this wavelength is chosen for noninvasive measurement utilising NIR Spectroscopy. The light intensity is found to be related to the sample thickness and sample constituent content.

The work by P.Daarani et.al [4], suggests that light scattering occurs in biological tissues due to a mismatch between the refraction indices of cellular components. Hence blood glucose can be determined by measuring the intensity of NIR light 940nm after passing through the fingertip. Beer Lambert law gives the link between the absorbance of light through any solution. The length path travelled by the light ray is proportional to the concentration of the solution and the length path travelled by the light ray. The hardware system consists of an Atmel SAM3X8E microcontroller. The model predicts blood glucose value using regression analysis. Clarke Error Grid Analysis or Surveillance Error Grid Analysis can both be used to check the system's accuracy.

Blank et.al [15], developed a system for measuring cholesterol and blood glucose levels in order to maintain track of patient health through a smart patient health tracking app. The sensors and microcontroller send out warning messages to the user via the mobile app when the system detects any abrupt changes in the patient's health state. Patient health tracking system using IoT successfully leverages wireless connection to monitor the patient's health in order to prevent emergencies.

Eko Agus Suprayitno et al.[17] propose a non-invasive blood sugar level monitoring system based on the Max30100 and IoT. The glucose level saturation is predicted using linear regression model.

The work by Rachel J. Dotson et.al [18] states that Cholesterol is well known for altering membrane and tissue permeability and physical characteristics. The author suggested that the total solubility of oxygen within the membrane is affected by high cholesterol concentration.

3. ORIGINALITY

The main aim of the proposed system is to divert from the traditional invasive methods and to develop a simple, reliable, painless, cost effective and portable Non-Invasive device for better monitoring of glucose and cholesterol levels in everyday life.

Various non-invasive optical spectroscopy like light absorption spectroscopy, photo acoustic spectroscopy, Raman spectroscopy, ultrasound, middle infrared spectroscopy, near infrared spectroscopy, fluorescence spectroscopy and Polarimetry. Among these Near Infrared Spectroscopy appears to be most suitable.

NIR spectroscopy enables the penetration of signals inside the tissue within the range of 1 to 100 millimeters depth. Penetration decreases when signal wavelength increases. As a result of increase in the glucose concentration, scattering properties decreases, increases the value of absorption coefficient and therefore the effective attenuation coefficient also increases which leads to the increase in the attenuation level.

The blood glucose is calculated by measuring the intensity of NIR light after passing through fingertip because light scattering occurs in biological tissues due to the mismatch between the refraction indexes of cellular components. According to Beer Lambert Law the equation is given by

$$\boldsymbol{A} \propto \boldsymbol{C} \tag{1}$$

where,

A-Absorption

C -Concentration

The sensor circuit would consist of NIR emitter and receiver. The fingertip is placed on the emitter. Saturated Peripheral Oxygen level and BPM are predicted. The values are passed through low noise analog signal circuit for processing and fine tuning of the signals. The inbuilt ADC block is used for converting the received analog signal to digital form. This digital signal is processed by using regression analysis to predict the blood glucose and cholesterol value.

4. SYSTEM DESIGN

The proposed system consists of Max30100 Sensor, Arduino and HC-05 Bluetooth module as shown in the Figure 1. It combines low noise analog signals to detect pulse and heart-rate signals. The device has two Light emitting diodes. One diode emits red light while another emits infrared light.

The heart pumps, oxygenated blood flow increases while when the heart relaxes, the oxygenated blood volume decreases. The difference in time between increase and decrease of oxygenated blood determines the pulse rate. The red light in the sensor is absorbed by deoxygenated blood more and passes the infrared light. On the other hand, the infra red light in the sensor is absorbed by oxygenated blood more and passes the red light.

The fingertip is placed on the emitter. The SPO2(Saturated Peripheral Oxygen level) and BPM (beats per minute i.e. heart rate) are predicted. The

BPM and SPO2 digital values obtained are given as inputs to the microcontroller. The BPM and SPO2 digital values obtained are given as inputs to the polynomial regression model. The regression model predicts the corresponding glucose values. In turn from the glucose value, corresponding voltage value is predicted for which cholesterol value is obtained. The glucose and cholesterol values are displayed on the LCD and are also sent to the mobile app through Bluetooth module.

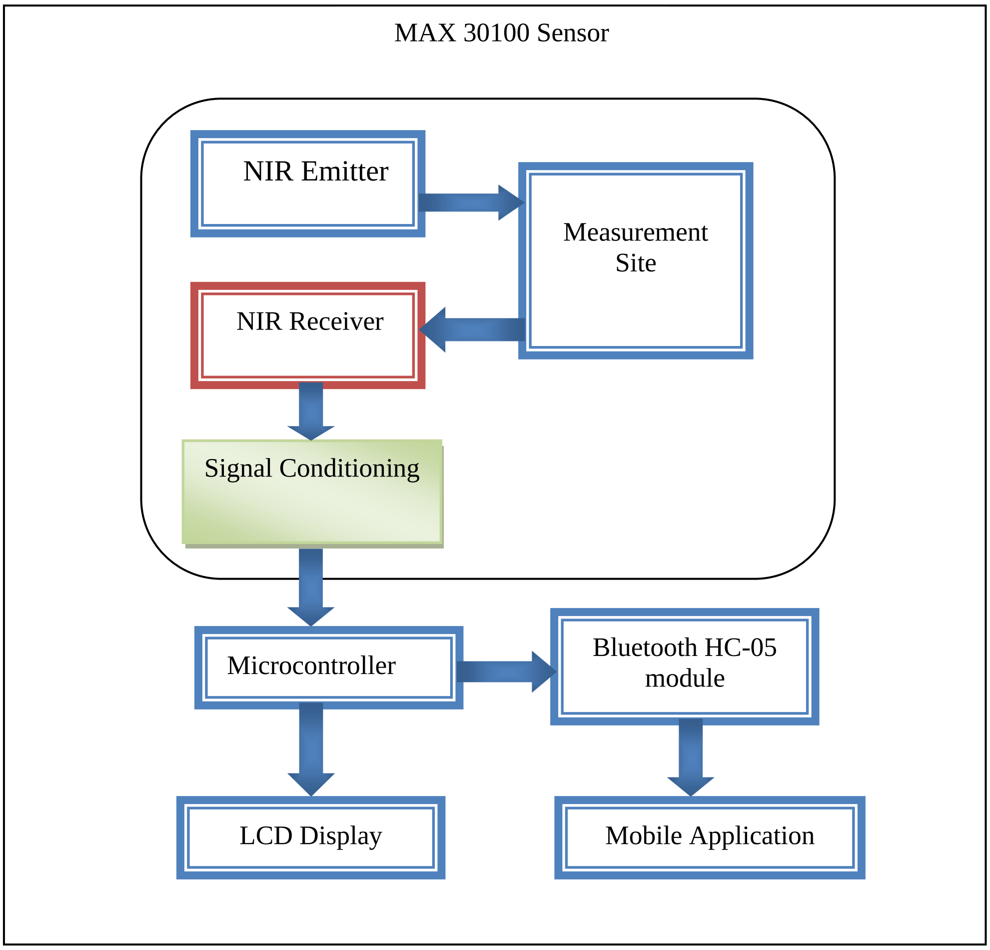

Figure 1. Block diagram of the proposed system

4.1 Software Methodology

The implementation is shown in the flowchart given in Figure 2. Once the arduino is connected to the PC/Laptop port the arduino is powered up and is ready to read values. The test subject's finger is placed on the sensor emitting the light. Suppose the values are not read properly, a message "PLACE FINGER PROPERLY" is displayed on the LCD and terminal window.

Once sensor reads valid BPM and SPO2 values, these values are recorded by Arduino and displayed in serial monitor of Arduino IDE platform. Arduino IDE establishes serial communication with PyCharm which sends the list of values for further processing.

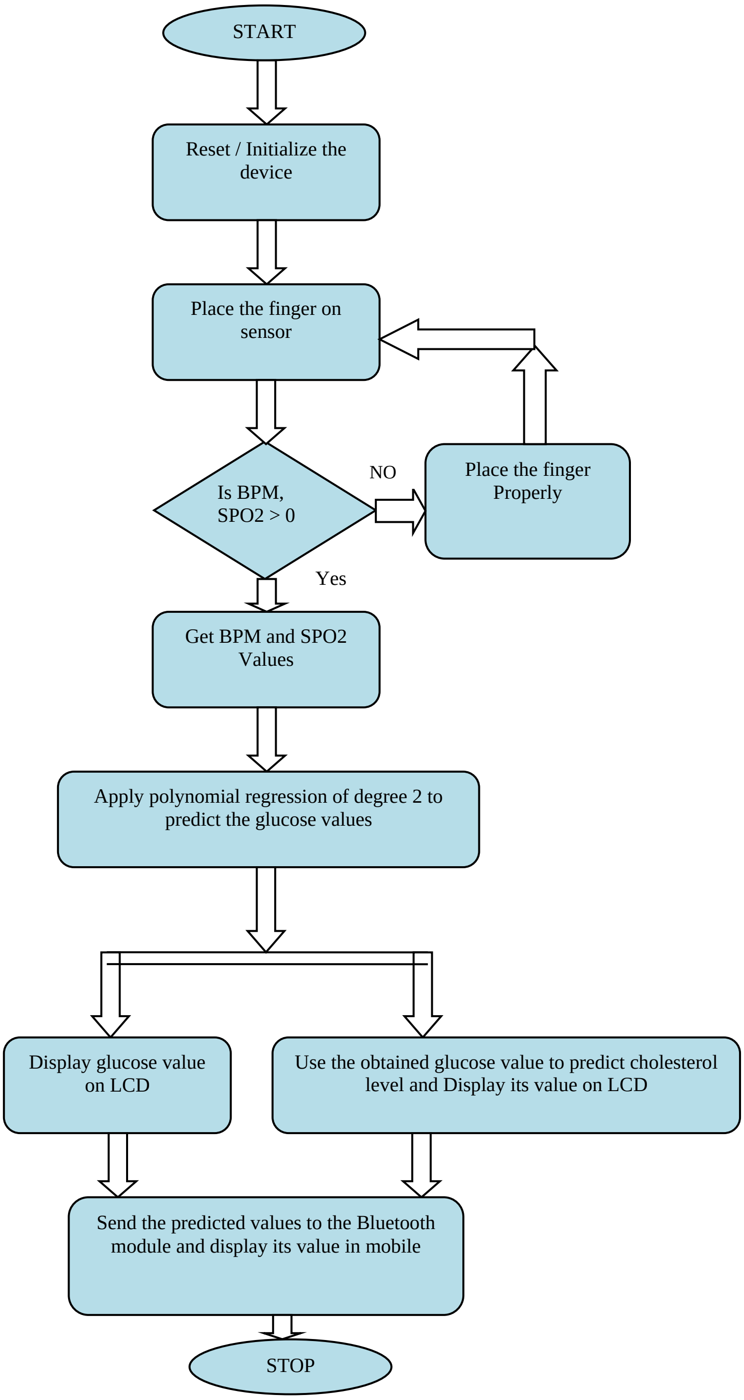

Figure 2. Flow Chart of the proposed system

An intermediate stable reading is selected from the list of values and is given as input for the polynomial regression model. The BPM and SPO2 values are not sufficient to build linear model as the data set contains less information. It necessitates the use of the Polynomial regression model to accurately predict the information. The inputs to the polynomial regression model are SPO2 and BPM which are the digital output from the sensor. As there are only two input vectors, to predict the values of glucose and cholesterol, more features are required which is obtained by using polynomial regression of degree 2. The squared input vectors and the product of the input vectors are used as new polynomial features. These polynomial features are fit into the polynomial regression model using the built in function in Python. The polynomial fitting is done as shown in Figure 3.

The polynomial regression equation for glucose prediction is given in equation (2).

$$Y= ax + cz + dz^2 + e \quad (2)$$

Where a, b, c, d and e are the co-efficient obtained by analyzing statistically. The co-efficient are obtained to minimize the cost function using the mean square error as explained with equation(3) Here, n is the number of samples taken. Yi is an observed value and yi hat is the predicted value.

$$c = \frac{1}{n}\left[\sum_{i=1}^{n}(y_i - \hat{y}_i)^2\right] \quad (3)$$

The equation is obtained by analyzing the data statistically as in equation (4) where x is BPM and y is SPO2.

$$\text{Predicted glucose level} = 16714.61 + 0.47^* x -351.045 ^*y + 1.85 ^*y^2 \quad (4)$$

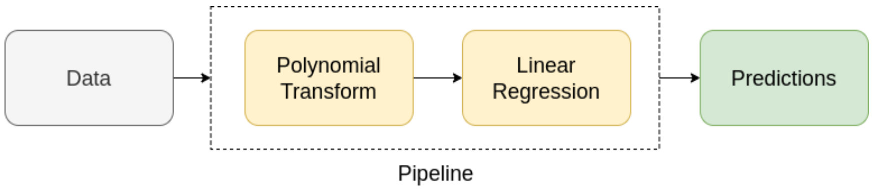

Figure 3. Polynomial fitting

The polynomial regression model is trained using predetermined datasets and regression co-efficient values are obtained from the trained model. The co-efficient values are used to predict the new required parameter value for the new sample inputs from the sensor. Thus, BPM and SPO2 values are used to predict the Glucose level concentration in the blood.

This glucose value acts as an input to the next algorithm which provides corresponding digital voltage values for the predicted glucose value. This voltage value is given as input for the final regression model which predicts the corresponding cholesterol value which is also trained by a set of pre-determined training datasets. The blood glucose and cholesterol values are displayed on the LCD Display and the same is sent to the mobile application created via Bluetooth HC-05 module which is displayed in the mobile application as well. The user can access the stored values in the Excel sheet.

5. EXPERIMENT AND ANALYSIS

The prototype of the proposed system is shown in Figure 3. The proposed system was tested on faculty and students of the Institute. Around 60 samples were tested in invasive and non-invasive method for comparison.

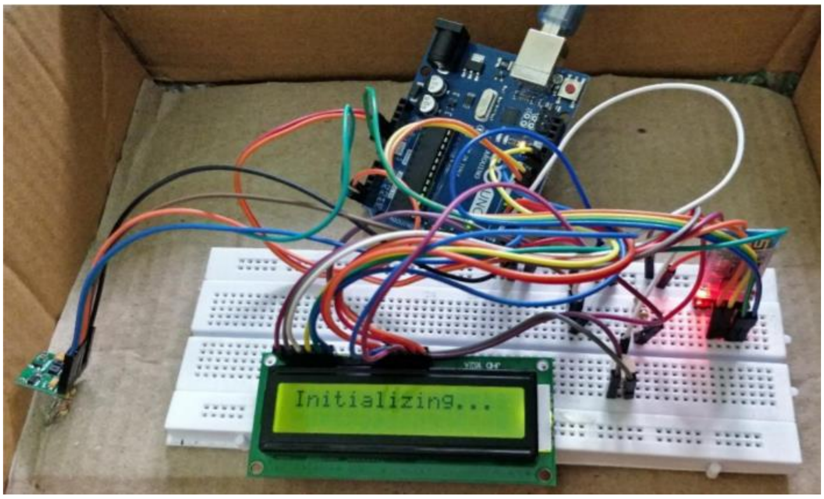

Figure3. Prototype of Developed System

The obtained Glucose values were validated with the values obtained invasively using glucometer. Figure 4., shows sample snap shots of glucose and cholesterol values obtained and displayed on LCD display. The same values are transferred to the mobile application by the Bluetooth module. The values are also stored in Excel sheet for continuous data storage and monitoring so that the same can be accessed by the doctors or the patients for health analysis.

.

Figure 4. LCD display of the predicted values

Figure 5. Invasive measurement of blood glucose level

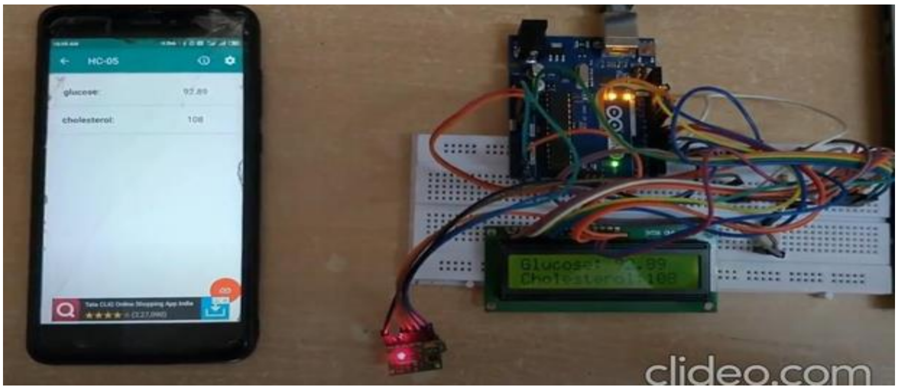

Figure 6. Non invasive values displayed on the LCD and mobile application

Table 1 summarizes the experimental blood glucose and cholesterol trial values measured by the proposed system for few subjects. The deviation in value for the predicted non-invasive values of glucose from the invasive values can be seen by measuring the variance and the standard deviation from regression model by fitting the curve.

Table 1. Experimental results for sample subjects

Subject	BPM	SPO2	Glucose by Invasive method	Glucose by non-Invasive method	Predicted Cholesterol Level
S1	68	97	102	104.033121	124.11
S2	82	98	123	120.387616	242.7
S3	74	98	114	116.612049	150.16
S4	61	92	110	107.499727	115.29
S5	78	98	117	118.499833	151.31
S6	99	98	131	128.410698	189.70
S7	71	98	113	115.196211	272.14
S8	76	94	102	100.769528	297.85
S9	71	97	104	105.448959	134.93
S10	78	97	106	108.752581	135.50

The deviation in value for the predicted non-invasive values of glucose from the invasive values can be seen in Figure 7.

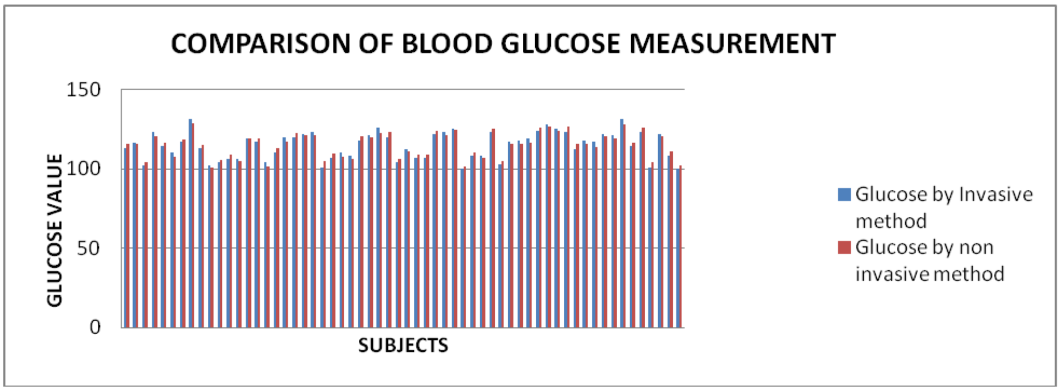

Figure 7. Comparative Graph of the glucose values

The variance for 60 subjects is summarized in Table 2. It is observed that by increasing the number of subjects, accuracy of the proposed model has increased and has an error tolerance of 2-5%. The error of the instrument can be significantly reduced by feeding more training datasets to the machine learning algorithm

Table 2. Mean Variance and Standard deviation

Total number of Subjects	Average Variance in Glucose by proposed method
60	2.56

6. CONCLUSION

Using the near-infrared absorption concept, a non-invasive glucose and cholesterol monitoring device was developed. This system was created with the goal of minimising the drawbacks of invasive blood glucose and cholesterol measurement techniques, and so does not require finger pricking or lancet strips. It's a simple gadget that doesn't require any technological knowledge. The projected output is also saved in a mobile application. This will enable users to continually monitor both blood glucose and cholesterol levels at the same time, allowing them to obtain timely treatment. When the acquired values are compared to the findings of glucose and cholesterol obtained using an invasive approach, the experimental results reveal that there is an average percentage error of 3-5%.

Despite the fact that our system can assess blood glucose and cholesterol levels, the precision of the measurements needs to be enhanced. Noninvasive blood glucose biosensors have never met the requirements for market commercialization due to a lack of precision and clinically acceptable accuracy. More accurate approaches can be developed by decreasing confusing factors. Furthermore, more measurements must be performed to make this system dependable and consistent, either by including a larger number of real-time data samples or by trying to adapt another machine learning technique.

Acknowledgments

We would like to thank the management and Principal of JSS Academy of Technical Education, Bengaluru for their moral support and encouragement. We would also like to thank all the lab technicians for the support in the lab. The project is funded by Karnataka State Council for Science and Technology under Student Projects Programme.

REFERENCES

[1] Manurung, Betty Elisabeth, et al, **Non-Invasive Blood Glucose Monitoring Using Near-Infrared Spectroscopy Based on Internet of Things Using Machine Learning**, *Proceedings of 2019 IEEE R10 Humanitarian Technology Conference (R10-HTC)(47129)*, Indonesia, pp. 5–11, 2019.

[2] Zheng T, Li W, Liu Y, Ling BW, **A noninvasive blood gluco se measurement system by arduino and near-infrared,** *Proceedings of 2016 IEEE International Conference on Consumer Electronics-China (ICCE-China),* China, pp. 1-3, 2016.

[3] Yusoff IM, Yahya R, Omar WR, Ku LC, **Non invasive cholesterol meter using Near Infrared sensor**, *Proceedings of 2015 Innovation & Commercialization of Medical Electronic Technology Conference (ICMET),* Malaysia, pp. 100-104, 2015.

[4] Daarani P, Kavithamani A, **Blood glucose level monitoring by noninvasive method using near infrared sensor,** *International Journal of Latest Trends in Engineering and Technology*, Vol. IRES 1, pp. 141-147, 2017.

[5] Anis SN, Alias R, **A Portable Non-Invasive Blood Glucose Monitoring Device with IoT**, *Evolution in Electrical and Electronic Engineering*, Vol. 2, pp. 36-44, 2021.

[6] N. H. Ahniar, G. R. Lestari and R. N. Hidayati, **A Non-Invasive Cholesterol Measuring Device Using a Photodiode Sensor With a BLYNK Interface**, *Proceedings of 2022 5th International Conference on Information and Communications Technology (ICOIACT)*, Yogyakarta, Indonesia, pp. 473-478, 2022.

[7] Gayathri B, Sruthi K, Menon KU, **Non-invasive blood glucose monitoring using near infrared spectroscopy**, *Proceedings of 2017 International Conference on Communication and Signal Processing (ICCSP)* , Chennai, India, pp. 1139-1142, 2017.

[8] Shinde AA, Prasad RK, **Non invasive blood glucose measurement using NIR technique based on occlusion spectroscopy**, *International Journal of Engineering Science and Technology (IJEST)*, Vol. 3, pp. 8325-8333, 2017.

[9] So CF, Choi KS, Wong TK, Chung JW, **Recent advances in noninvasive glucose monitoring**, *Medical Devices: Evidence and Research,* pp.45-52, 2022.

[10] Narkhede P, Dhalwar S, Karthikeyan B, **NIR based non-invasive blood glucose measurement**, *Indian Journal of science and technology*, Vol. 9, pp. 1-5, 2016.

[11] Ali H, Bensaali F, Jaber F, **Novel approach to non-invasive blood glucose monitoring based on transmittance and refraction of visible laser light**, *IEEE access,* Vol. 5, pp. 9163-9174, 2017.

[12] Devakumar VJ, Ravi T, Karthikeyan S, **Review on Non Invasive Glucose and Cholesterol Measurement System**, *Proceedings of IOP Conference Series: Materials Science and Engineering,* Tamil Nadu, India, Vol. *590,* 2019.

[13] Asekar MS, **Development of portable non-invasive blood glucose measuring device using nir spectroscopy**, *Proceedings of 2018 Second International Conference on Intelligent Computing and Control Systems (ICICCS)*, Madurai, India, pp. 572-575, , 2018.

[14] Sunny S, Kumar SS, **Optical based non invasive glucometer with IoT,** *Proceedings of 2018 International Conference on Power, Signals, Control and Computation (EPSCICON)*, Thrissur, India, pp. 1-3, 2018.

[15] Blank, Thomas B., Timothy L. Ruchti, Alex D. Lorenz, Stephen L. Monfre, M. R. Makarewicz, Mutua Mattu, and Kevin Hazen, **Clinical results from a noninvasive blood glucose monitor**, *Optical Diagnostics and Sensing of Biological Fluids and Glucose and Cholesterol Monitoring II*, Vol. 4624, pp. 1-10, 2002.

[16] Apar V, Autee DR, **Development of Portable Device for Measurement of Blood Glucose, Temperature and Pulse-Oximeter using Arduino**, *International Research Journal of Engineering and Technology (IRJET)*. Vol. 6, pp.1758-1761, 2019.

[17] Suprayitno EA, Setiawan A, Dijaya R, **Design of Instrumentation in Detecting Blood Sugar Levels with Non-Invasive Technique Base on IoT (Internet of Things),** *International Journal of Engineering & Technology*, Vol. 7, pp 440-442, 2018.

[18] Dotson RJ, Smith CR, Bueche K, Angles G, Pias SC, **Influence of cholesterol on the oxygen permeability of membranes: insight from atomistic simulations**, *Biophysical journal*, Vol. 112, No. 11, pp. 2336-2347, 2017.

[19] Hina A, Saadeh W, **Noninvasive Blood Glucose Monitoring Systems Using Near-Infrared Technology—A Review**, *Sensors*, Vol. 22, No. 13, pp. 4855, 2022.

[20] Hina A, Saadeh W, **A noninvasive glucose monitoring SoC based on single wavelength photoplethysmography,** *IEEE Transactions on Biomedical Circuits and Systems,* Vol. 14, No. 3, pp. 504-515, 2020.

[21] Shubha B, Anuradha M G, Suprada H S, Sumedha C, Prathiksha R V, Shrilaxmi Dixit, **A Study on Non-Invasive Blood Glucose and Cholesterol Monitoring Device**, *High technology* letters, Vol. 27, No. 7, pp. 353-361, 2021.

[22] Kumar, D. Arul, T. Jayanthy, **Review on non-invasive blood glucose measurement techniques,** *Proceedings of the 2020 International Conference on Communication and Signal Processing (ICCSP),* India, pp. 981-986, 2020.

[23] Yu Yan, Huang J, Zhu J, Liang S, **An accurate noninvasive blood glucose measurement system using portable near-infrared spectrometer and transfer learning framework**, *IEEE Sensors Journal*, Vol. 21, No. 3, pp. 3506-3519, 2020.

[24] Darmawan HY, Sanubari A, Saida N, Fauzi RN, Ristiani N, Oktivasari P, Wardhani RN, **Non-Invasive IoT Home Medical Check-up Programming to Monitor Blood Sugar, Cholesterol, Uric Acid, and Body Temperature**, *Proceedings of 2022 5th International Conference of Computer and Informatics Engineering (IC2IE),* Indonesia, pp. 236-240, 2022.

[25] Jain P, Joshi AM, Mohanty S, **Everything you wanted to know about continuous glucose monitoring,** *IEEE Consumer Electronics Magazine,* Vol. 10, No. 6, pp. 61-66, 2021.